BULLETIN OF
IOWA STATE COLLEGE
OF AGRICULTURE AND MECHANIC ARTS

Vol. XII. August 15, 1913 No. 10.

House Heating Fuel Tests

BY

W. H. MEEKER and H. W. WAGNER

BULLETIN 33.
ENGINEERING EXPERIMENT STATION

Ames, Iowa

Published Semi-Monthly by the Iowa State College of Agriculture and Mechanic Arts. Entered as Second-class Matter, October 26, 1905, at the Post Office at Ames, Iowa, under the Act of Congress of July 16, 1904.

PURPOSE OF THE STATION

THE purpose of the Engineering Experiment Station is, first, to afford a service for the other industries of Iowa, similar to that afforded by the Agricultural Experiment Station to the agricultural industries; second, to assist the urban population of the state in solving the technical problems of urban life; third, to solve the purely engineering problems of the agricultural population and industries of the state.

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HOUSE HEATING FUEL TESTS

I. INTRODUCTION

Article 1. Nature of Investigations. The amount of fuel burned in the average house heating plant is small compared with that consumed by a power plant, yet the very much larger number of houses and other buildings heated by independent hot air furnaces and boilers make the aggregate of coke and coal burned by them no small item. A conservative estimate places the number of dwellings in Iowa equipped with house heating furnaces and boilers at not less than 100,000. At an annual average fuel cost of $65.00 each, which is also a low estimate, the amount paid out each year is 6½ million dollars for warming the homes of Iowa that are equipped with such house heating plants. Other millions are spent for heating stores, office buildings, etc., and for fuel burned in heating stoves. It is not hard to see the saving to the State to be gained by choosing such fuels as will save a few per cent on the above amounts, or by choosing such fuels as will reduce the care of fires and the damage from dirt and smoke to a minimum.

Because of inquiries on the relative value of fuels, and because the large need of reliable data on these points was realized, the Engineering Experiment Station undertook the problem and decided to test as many as practicable of the coals and cokes commonly used in Iowa for house heating work.

For this purpose a steam house heating boiler was employed. Steam boilers are not used in a majority of house heating plants, but the heat absorbed by steam can be measured so much more accurately than heat absorbed by either water or hot air, and principally for that reason the steam boiler was chosen. The boiler used had also a greater capacity than the average house heating plant which cuts down errors of observation inherent in a smaller plant. It is true too that many different types as well as sizes of boilers and furnaces are in common use, yet the writers believe that the comparative results obtained will hold true to a large degree in the different types and sizes.

The investigation at Ames included 38 general efficiency tests upon 20 different fuels, 11 special efficiency tests made upon some of the same fuels and a few other special tests made upon some of the same fuels.

Tests upon 7 fuels with two types of boilers at the Engineering Experiment Station of the University of Illinois show in

general the same order of efficiencies for the different classes of fuels. The three boilers used at the two stations are all of different types and rated capacities.

Article 2. Acknowledgements. The writers wish to acknowledge much value derived from the suggestions and source for comparison of test data embodied in Bulletin No. 31 of the Engineering Experiment Station of the University of Illinois, Urbana, Illinois, by J. M. Snodgrass, entitled "Fuel Tests With House Heating Boilers."

The boiler used in the tests at Ames was kindly loaned by the American Radiator Company of Chicago, Illinois. It was set up and tests were made upon it early in 1911 by Messrs. J. H. Burlingame and F. H. Morris. The results of their tests were written up for their graduating thesis for the degree of B. S. in M. E. at the Iowa State College. Some of the data in the thesis are used for comparison in this bulletin. The writers of this bulletin were also assisted with some of their first tests in the winter of 1911-12, by Messrs S. E. Lacey, G. H. Montillon and H. W. Lindeman, who were then senior students in the Department of Mechanical Engineering at the Iowa State College.

II. OBJECT OF TESTS

Article 3. Original Purpose. The primary object of these tests was to determine the fuel cost for developing a definite amount of heat in an available form, as well as the attention required and inconvenience experienced in keeping up heat with the different fuels.

It is the purpose of the writers to present the most concrete conclusions and data under three heads—Summary of Results, Heating Costs, and Fuels—for the benefit of those having ordinary knowledge of fuels and heating and who may wish to derive the practical benefits to be had for the minimum amount of study. For the benefit of those who wish more information on the subject, or who are interested more from the standpoint of science and research, further discussions, tables and diagrams follow under other heads.

It is hoped also that deductions contained herein may be of some value in the management of boilers used for power purposes.

Article 4. Related Points of Consideration and Outline. As the tests went on points in addition to those in mind at the beginning were thought to be worth study. The principal subjects discussed through the bulletin might be classified as follows:

A. Fuel Costs.
  1. Actual for equivalent evaporation of 1,000 pounds of water from and at 212° F.
  2. Calculated for heating an 8-room house for one season.
B. Cleanliness.
  1. Dirt and dust in fuel.
  2. Smoke and soot from fire.
C. Attention.
  1. Starting fire.
  2. Life of a fuel charge.
  3. Poking and leveling required in fire box.
  4. Clinker and ash.
D. Fixed Carbon and Efficiency.
E. Size of Fuel and Efficiency.
F. Amount of Fuel Charge and Efficiency.
G. Depth of Fuel Bed and Efficiency.
H. Capacity and Efficiency.
I. Dampers and Efficiency.
J. Minor Details and Data Incident to Boiler Trials.
  1. Proximate and calorific analysis of fuel.
  2. Drafts.
  3. Temperatures.
  4. Flue gas analysis.
  5. Evaporative performance.
  6. Efficiencies.
  7. Boiler balance, and
  8. Other data.

III. SUMMARY OF RESULTS.

Article 5. General. Among the points to be considered in judging a fuel for house heating work the following are of most importance—Evaporative cost, ease of starting fire, dirt, dust and gas encountered in firing, smoke and soot deposits, clinker, ash and refuse to dispose of, and general attention in firing. The relative importance of these points depends upon the service required. For large units the evaporative cost will perhaps come first. For small units in dwelling houses, the general question of cleanliness in the boiler room as well as through the whole house is very important. In still other cases a fuel, one charge of which will give a constant heat without attention over a long period of time, should be the one chosen.

For the ordinary dwelling of about 8 rooms, the best grades of soft coal tested, such as Illinois Little Jack or Tennessee Smokeless, would perhaps give the best all round satisfaction.

In many cases it would be advantageous to have on hand a small variety of fuels. For instance, Kentucky Red Torch

could be used for kindling and for building up a low fire quickly, a cheap Iowa coal could be used during the day and the fire could be banked at night with Tennessee Smokeless. In extreme cases, where the furnace has to be left for longer time without attention, anthracite could be used.

The value of Iowa coals would be greatly increased if a cheap process of coking, whereby the greater part of both fixed carbon and volatile combustible could be saved and used after separation, could be perfected.

Prices based upon heat units, in a certain kind of fuel, rather than upon its actual weight would be more just to both the operator and consumer.

Article 6. Fuel Costs. Of all fuels tested, the Iowa soft coals are the cheapest in both cost per ton and evaporative cost.

Costs depend largely upon the distance a fuel has to be hauled. Anthracite and eastern solf coa s would make cheaper fuels were it not for this factor.

The cost of preparing and transporting peat practically prohibits its use as a fuel in any part of the state.

Anthracite is the most costly fuel of those tested now used to any extent for house heating in this state.

At the same price per ton, fuels high in fixed carbon will be less costly to use.

Fixed carbon can be purchased more cheaply in the form of coke or in such high fixed carbon fuels as Tennessee Smokeless than in the form of anthracite.

The cost per British thermal unit is the lowest in Iowa coals; is the highest in anthracite, petroleum coke and peat; and is lower in Illinois coals than in gas-house and Solvay cokes.

The cost per ton based upon fixed carbon content is the lowest in Iowa coals, Solvay and gas-house coke; is the highest in anthracite, petroleum coke and peat; and is higher in Illinois than in Iowa coals.

Freshly mined coal gives the best results.

Table I, page 11, is a summary of the average, minimum, and maximum heating costs for the different classes of fuels tried. The prices per ton of Iowa coals include a freight haul of about 50 miles. The prices per ton of foreign fuels include the freight rate to Ames which is near the center of the state. Thus it is evident that for certain localities as in some eastern and northern parts of the state the relative length of haul is greater for Iowa coals which would consequently be more favorable to foreign fuels.

Table I does not include tests on mixtures of coke and coal, nor those made when the capacity developed was far from 60%

of the builder's rating. The prices per ton are averages of the cost of fuels of the same class used in the tests, and the evaporative and season costs are averages of the costs in the different tests.

TABLE I.

SUMMARY OF EVAPORATIVE COSTS.

Class of Fuel	No. of tests	No. of fuels	No. of short firing tests	No. of long firing tests	Ave. cost per ton	Cost per 1000 lbs. equiv. evap. (212° F.)			Season cost for 8 room house		
					$	ave. ¢	min. ¢	max. ¢	ave. $	min. $	max. $
Iowa soft coals	15	6	8	7	3.86	37.4	32.4	53.5	64.70	56.00	92.50
Illinois soft coals	11	5	7	4	4.70	40.6	37.3	43.3	70.10	64.50	74.90
Other soft coals	3	2	1	2	6.87	47.1	41.6	50.7	81.40	71.90	87.50
Cokes	6	4	4	2	8.50	52.3	41.3	64.3	90.50	71.50	111.10
Anthracite	2	2	1	1	9.50	61.8	57.8	65.8	106.90	100.00	113.90
Iowa peat	1	1	1	0	4.50	144.1	144.1	144.1	249.00	249.00	249.00
Total	38	20	22	16							
Average					5.90	45.6			78.80		

The average season cost for each fuel is illustrated in Fig. 1, page 12.

Article 7. Conditions Affecting Efficiency. Soft coals yield a higher efficiency when a greater per cent of the heat value of the fuel is contained in the fixed carbon, and the results obtained indicate a very close relation between the two quantities.

The average efficiencies of coke and anthracite are above the average of soft coals, but are not high enough to bear out the same relationship between fixed carbon and efficiency that holds for soft coals.

Cokes lowest in volatile matter were found to give better efficiency than those containing an appreciable per cent of volatile combustible as petroleum coke.

No appreciable gain was secured by burning a mixture of soft coal and coke.

There is considerable opportunity for improvement in the type of furnace and boiler used for burning soft coals.

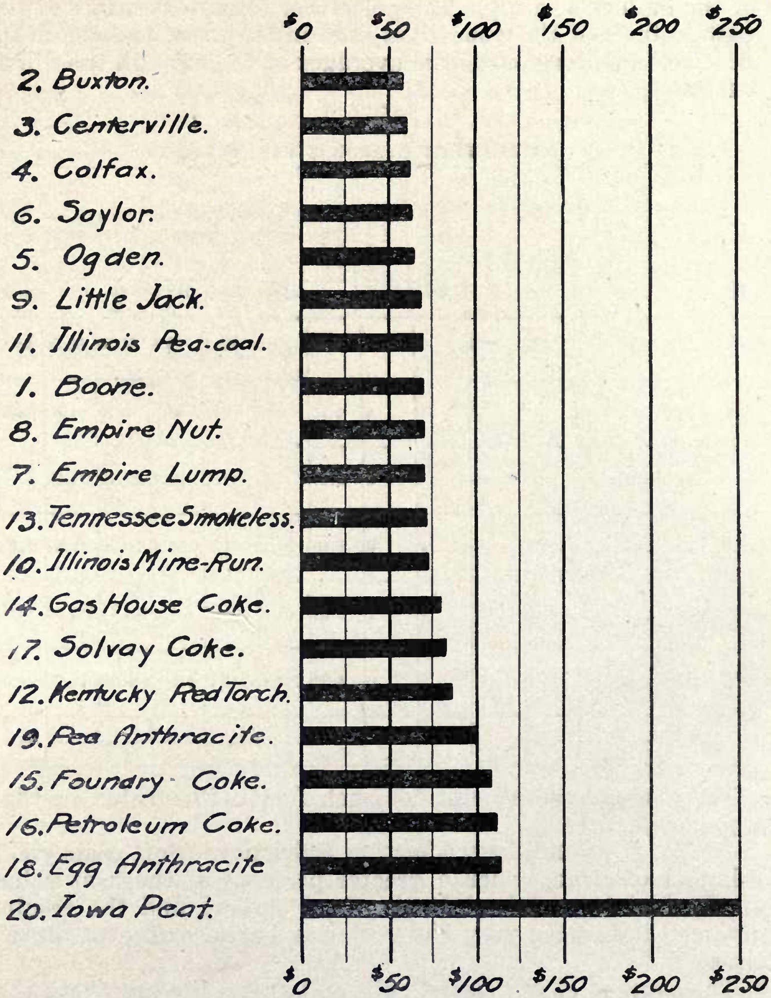

Fig. 1.—Season costs with Fuels Tested. Each heavy horizontal line represents a fuel cost derived from the averages of all tests on that fuel according to the calculations explained in Art. II.

In general a higher efficiency may be reached by observing the following suggestions:

(a) Use lumps just small enough to be fired conveniently instead of fuel broken into small pieces.

(b) Fire at one time a large charge nearly filling the fire box rather than a small charge of about 100 pounds as required.

(c) Keep a deep bed of coals.
(d) Develop from 40% to 75% of the rated capacity of the boiler when soft coals are used.
(e) Allow no cold air to enter the flues or fire box above the grates.
(f) Provide a good natural draft and permit a free passage for the gases from the furnace to the chimney.
(g) Keep the boiler heating surface clean from soot and ashes.
(h) Maintain constant conditions, such as the air supply, supply and temperature of feed water, drafts and rate of heat drawn from furnace.
(i) Avoid large holes and "dead spots" in the fire.

Article 8. Attendance and Cleanliness. Cokes are the most difficult to kindle and require the deepest bed of coals to keep the fire alive.

Soft coals are the easiest to kindle and the fire will remain alive when the depth of bed is as low as a couple of inches. Illinois coals have more snap than the Iowa coals in this respect. Kentucky Red Torch is remarkable in the ease with which it can be ignited.

Illinois and especially Iowa coals are unpleasant to burn because of the sulfur and other gases and fumes likely to escape in a dwelling.

The cokes and anthracite are the cleanest to handle, do not clinker, do not cake, yield little smoke, deposit little soot and have less tendency to form holes in the fire than other fuels.

The soft coals require more frequent attention than coke and anthracite on account of caking, clinkering and tendency to form holes in the fire.

The soft coals require more frequent firing than anthracite because of the comparative short life of one charge.

The amounts of ash and refuse to be handled vary considerably with different lots of the same fuel. About the only general statement that can be made is that the ash and refuse is large per useful unit of heat for Iowa coals. It is very low for petroleum coke.

IV. HEATING COSTS AND FUEL VALUES.

Article 9. Fuel Prices. Most of the fuels were bought from dealers in Ames at different times. The prices per ton of these as well as the prices of fuels secured in other ways were all equalized to the same basis as nearly as possible. This basis was the cost per ton of 2,000 pounds delivered in two ton lots to the customer's bins in Ames at the beginning of the heating season in the autumn of 1912. Prices of fuels shipped di-

TABLE II.

AVERAGE FUEL COSTS AND VALUES.

No. of orders	No. of tests	Long firing tests	Short firing tests	FUEL: Numder	FUEL: NAME	Fuel prices: Per ton fuel as fired	Fuel prices: Per ton fixed carbon	Fuel prices: Per million B. T. U.	Evaporative Costs, At actual price: Per 1000 lbs. equiv. evap. (212 oF.)	Evaporative Costs, At actual price: Per season for 8 room house	Evaporative Costs, At actual price: Per 1000 square feet radiation per hour	Evaporative Costs, At $.100 per ton: Per 1000 lbs. equiv. evap. (212 oF.)	Evaporative Costs, At $.100 per ton: Per season for 8 room house	Evaporative Costs, At $.100 per ton: Compared with egg anthracite @ 100 %	Comparative evaporative value per ton: With Centerville Coal @ $4	Comparative evaporative value per ton: With egg anthracite @ 100%
						$	$	c	c	$	c	c	$	%	$	%
3	5	1	4	1	Boone	3.75	9.43	17.7	40.6	70.10	1.02	10.8	18.70	61.7	3.20	59
1	2	2	0	2	Buxton	3.75	8.58	17.7	33.4	57.70	.84	8.9	15.40	50.7	3.90	72
1	2	1	1	3	Centerville	4.00	8.61	16.1	35.0	60.50	.88	8.8	15.10	53.2	4.00	74
1	2	1	1	4	Colfax	3.75	8.90	16.3	36.2	62.60	.91	9.7	16.70	55.0	3.60	67
1	2	1	1	5	Ogden	4.00	9.76	17.3	37.6	65.00	.94	9.4	16.25	57.1	3.70	68
1	2	1	1	6	Saylor	3.90	9.18	16.6	36.9	63.80	.93	9.5	16.40	56.0	3.70	68
1	2	1	1	7	Emp. Lump	4.75	10.76	20.6	40.9	70.70	1.03	8.6	14.90	62.1	4.10	76
1	2	1	1	8	Emp. Nut	4.50	9.90	19.7	40.8	70.60	1.02	9.1	15.70	62.0	3.90	72
3	3	1	2	9	Little Jack	5.50	10.02	22.7	39.5	68.20	.99	7.2	12.40	60.0	4.90	91
1	2	0	2	10	Ill. Mine Run	4.75	11.44	22.4	42.3	73.10	1.06	8.9	15.40	64.3	3.90	72
1	2	1	1	11	Ill. Pea-coal	4.00	9.14	17.6	39.8	68.70	1.00	10.0	17.20	60.5	3.50	65

1	2	1	1	12	Ken. Red Torch	6.50	11.58	22.0	49.8	86.00	1.25	7.7	13.20	75.6	4.60	85
1	1	1	0	13	Tenn. Smokeless	7.25	10.60	27.5	41.6	71.90	1.01	5.7	9.90	63.2	6.10	113
1	1	0	1	14	Foundry coke	8.50	10.11	33.7	62.6	108.00	1.57	7.4	12.70	95.2	4.80	89
2	2	0	2	15	Gas-house coke	7.00	8.50	28.5	46.1	79.60	1.15	6.6	11.40	70.0	5.30	98
1	1	1	0	16	Petroleum coke	10.25	11.90	31.5	64.3	111.10	1.61	6.3	10.80	97.8	5.60	104
1	2	1	1	17	Solvay coke	8.25	9.53	32.0	47.4	82.00	1.19	5.7	9.90	72.0	6.10	113
1	1	1	0	18	Egg anthracite	10.25	11.88	37.3	65.8	113.80	1.65	6.4	11.10	100.0	5.40	100
1	1	0	1	19	Pea-anthracite	8.75	11.00	33.6	57.8	100.00	1.45	6.6	11.40	88.0	5.30	98
1	1	0	1	20	Iowa peat	4.50	36.00	64.2	144.1	249.00	3.62	32.0	55.30	219.0	1.10	20

rectly to the Station were equalized by comparing prices at the mine, drayage and dealer's profits, and by using a freight rate of 66c which represents the freight charges upon one ton hauled 50 miles by rail. Iowa coals purchased from local dealers were all mined within a radius of 50 miles from Ames. Prices on fuels from outside the state included of course the actual total freight charges to Ames.

The price of Iowa peat is based upon a \$3.00 value at the works for a ton of peat containing 30% moisture.

Table II, page 14, quotes the prices used per 2,000 pounds for the fuel as fired.

Article 10. Evaporative Costs. The cost of fuel required to evaporate 1,000 pounds of water from and at 212° F. is taken as the most convenient unit of evaporative cost. This amount of evaporation is the equivalent of supplying 400 sq. ft. of radiation for 10 hours at the rate of .25 pound per square foot per hour. In table XIII will be found also the costs of evaporating 1,000 pounds of water under actual conditions. The ratio between the actual and "equivalent evaporation" is nearly 6:7 in all tests.

Table II, page 14, presents the average evaporative costs with each fuel at the actual prices and at a theoretical price of \$1.00 per ton. The latter is of convenience for calculating evaporative costs where ton prices are different than used in table II. The same table gives the comparative evaporative value per ton of each, taking Centerville coal, the best Iowa fuel tested, at \$4.00 as a basis for comparison. The comparative evaporative value based upon anthracite at 100% is also given.

Article 11. Season Costs. For better illustrating the effect of evaporative cost upon season cost, figures have been prepared for application to a supposed 8-room house equipped with steam heating plant. Assumptions and calculations are as follows:

> 8-room dwelling, with an average of 40 sq. ft. of radiation per room.
>
> Heating system in use during the 5 months of November, December, January, February and March.
>
> Steam consumption at full capacity, 0.25 pound of steam from and at 212° F. per hour per square foot of radiation.
>
> Average per cent of full capacity of radiating surface served, 60.
>
> Fuel efficiency, same as determined for each fuel as presented in this bulletin.
>
> 5 months $\times$ 30 days $\times$ 24 hours $=$ 3600 hours per season.

8 rooms × 40 sq. ft. = 320 sq. ft., total radiating surface.

320 sq. ft. × 0.25lb × 60% = 48lb, average equivalent evaporation per hour for the season.

48lb × 3600 hrs. = 172,800lb steam from and at 212° F. required per season.

172,800 ÷ 1000 × Evaporative Cost = Season Cost.

The average of tests with Iowa coals brings the season cost to about $70.00 which is within the limits of actually observed costs in different dwellings in Ames, where different types of heating plants are installed.

The fuels are arranged in figure 1, page 12, from the figures quoted in table II in the order of their season costs.

No data of tests on hot air and hot water heating plants are available, yet it is only fair to assume that the same general order of fuel costs would apply to all three types of heating plants.

Table II is made up of the same general tests as are included in Table I. The column headed, "No. of Orders," refers to the number of different samples or lots of each fuel tested.

The high cost with Boone coal as compared with other Iowa coals is due largely to an extremely low efficiency from one lot of Boone coal.

In some sections of the state, wood is still used for domestic heating. The following figures are selected from a table in Gebhardt's Steam Power Plant Engineering.

	Pounds per Cord	B. T. U. per Pound
Hickory	4500	5400
White Oak	3850	5400
Willow	1920	6830

Using the above figures and assuming that a B. T. U. derived from wood has the same value as one derived from Centerville coal (12,450) at $4.00 per ton, the woods would have the following values, per cord:

	Equivalent Pounds of Coal	Value in Dollars
Hickory	1950	3.90
White Oak	1670	3.30
Willow	1050	2.10

V. FUELS.

Article 12. General. The Buxton, Centerville and Colfax coals were shipped from the mines in sacks directly to the Station in quantities of 1000 pounds each.

TABLE III.

FUELS—ANALYSIS AND SOURCE.

Number	Name	Source	Grade	Approximate average size of fuel as received	Heat value per pound, dry	Fuel as Fired: Moisture.	Fuel as Fired: Volatile Matter	Fuel as Fired: Fixed Carbon	Fuel as Fired: Ash	Fuel as Fired: Heat value per pound
				Ins.	B.T.U.	%	%	%	%	B.T.U.
1	Boone	Boone County, Iowa	lump	3 to 12	11,720	9.7	37.8	39.8	12.7	10,600
2	Buxton	Monroe County, Iowa	lump	7 to 8	11,530	8.2	36.5	43.7	11.6	10,600
3	Centerville	Appanoose County, Iowa	lump	5 to 6	13,700	9.2	37.5	46.5	6.8	12,450
4	Colfax	Jasper County, Iowa	lump	6 to 8	12,610	8.5	39.1	42.2	10.2	11,540
5	Ogden	Boone County, Iowa	lump	5 to 6	13,130	12.0	40.4	41.0	6.6	11,560
6	Saylor	Polk County, Iowa	lump	8 to 10	12,400	5.5	40.8	42.5	11.2	11,720
7	Empire Lump	Peoria District, Illinois	lump	5 to 6	12,380	6.9	37.3	44.1	11.7	11,520
8	Empire Nut	Peoria District, Illinois	nut	1.5 to 2	12,450	8.3	33.9	45.4	12.4	11,410
9	Little Jack	Franklin County, Illinois	lump	6 to 7	12,840	5.8	31.8	54.8	7.6	12,100
10	Illinois Mine Run	Menard County, Illinois	mine run	4 to 5	11,610	8.8	33.6	41.5	16.1	10,600
11	Illinois Pea-coal		pea	.5 to .75	12,220	7.1	35.6	43.8	13.5	11,350
12	Kentucky Red Torch	Cumberland District, Kentucky	lump	5 to 7	15,100	2.0	38.5	56.2	3.3	14,800
13	Tennessee Smokeless	Tennessee	lump	3 to 4	13,310	0.9	15.9	68.3	14.9	13,190

14	Foundry coke			4 to 5	12,780	1.1	2.0	84.0	12.9	12,630
15	Gas-house coke			4 to 5	12,490	1.7	2.4	82.3	13.6	12,280
16	Petroleum coke	Petroleum refineries		4 to 5	15,110	1.7	10.3	86.1	1.9	14,850
17	Solvay coke			3 to 4	12,950	0.5	2.0	86.6	10.9	12,890
18	Egg Anthracite	Pennsylvania	egg	2.5 to 3.5	13,940	1.4	6.1	86.3	6.2	13,750
19	Pea-anthracite		pea	.5 to .75	13,350	2.4	6.8	79.5	11.3	13,020
20	Iowa peat	Worth County, Iowa	machine	1 to 2	6,390	45.2	25.8	12.5	16.5	3,500

The Illinois mine run and pea-coal and the pea-anthracite and foundry coke were taken from the College fuel supply in bulk in such quantities as were required for the tests.

The Iowa peat was picked from a one ton sample which had been shipped to the Mining Department of the College from the works near Fertile, Iowa, a few years previous. It had been taken from the Goose Lake peat beds in Worth County, and had been machine pressed. The sample had been stored under shelter at Ames, but had been tramped upon and gathered a great deal of moisture. When fired it was not completely air dried and was broken up much more than fresh machine peat would have been. The test was made mainly to determine the efficiency of peat as compared with that of soft coals.

All cokes and coals not mentioned above were purchased from dealers at Ames and were delivered sacked in quantities of from 200 to 1000 pounds each.

The large lumps of coal were broken so that no pieces over 6 inches in diameter were used in any tests except No. 46 on Buxton coal.

Table III, page 18, gives the sources and composite analyses of the fuels, and Table IV, page 21, is descriptive of different observed characteristics.

The wide variation in the size of Boone coal is due to a smaller average size in one lot.

The life of fuel charge in Table IV is comparative and assumes that each fuel charge evaporates the equivalent of 200 pounds of water from and at 212° F. per hour, which corresponds to about 60% of the boiler rating. The weight per fuel charge was calculated by using the following weights per cubic foot: Anthracite, 50 pounds; soft coal, 40 pounds; coke, 28 pounds; peat with 30% moisture, 20 pounds.

No attempt was made to determine the density of the smoke according to any convention. In color the smoke varied with different fuels and stages of fire from reddish brown through gray to black.

Article 13. Iowa Coals. The Iowa coals tested, 6 in number, and all of lump grade, are fairly representative of those occurring in the central and south central parts of the state, and the results obtained should give a good approximation of the value of other Iowa coals when the proximate and calorific analyses are known as explained in Article 19 on Fixed Carbon and Efficiency. Considerable variation was noted between different Iowa coals. The following description is general.

As stated in the summary, Iowa coals are high in sulfur and in the smoke producing hydro-carbons. When fired under ordinary circumstances considerable inconvenience is experi-

TABLE IV.

FUEL CHARACTERISTICS.

No.	Fuel	Difficulty of kindling	Dirt and dust	Fusion and coking	Smoke and soo	Clinker	Approximate life of full charge, in hours
1	Boone	H	H	L	H	H	6.9
2	Buxton	H	H	H	M	M	8.4
3	Centerville	M	M	L	M	S	8.6
4	Colfax	VH	VH	L	H	H	7.8
5	Ogden	H	H	L	H	L	7.9
6	Saylor	H	H	L	H	H	7.9
7	Empire Lump	M	M	M	M	L	8.7
8	Empire Nut	M	M	M	M	L	8.3
9	Little Jack	L	L	S	L	S	10.5
10	Ill. Mine Run	H	H	L	M	M	8.4
11	Ill. Pea-coal	M	L	H	M	VH	7.6
12	Ken. Red Torch	S	L	VH	M	N	9.9
13	Tenn. Smokeless	L	M	H	L	N	13.0
14	Foundry coke	VH	S	N	S	N	7.1
15	Gas-house coke	VH	S	N	S	N	8.0
16	Petroleum coke	H	S	N	S	N	8.4
17	Solvay coke	VH	S	N	S	N	9.2
18	Egg Anthracite	H	S	N	S	N	14.6
19	Pea-anthracite	H	S	N	S	N	14.3
20	Iowa Peat	M	M	S	L	VH	1.5

Explanation of symbols—
VH, very high.
H, high.
M, moderate.
L, low.
S, slight.
N, practically none.

enced because of the sulfur fumes, smoke and soot. Sulfur determinations were not made in connection with these tests, but most Iowa lump coals contain an average of 4% to 6% of sulfur. Clinkering is another source of inconvenience encountered in the burning of Iowa coals. As a rule they contain a few per cent more ash, and have less fixed carbon than do the Illinois and eastern soft coals. The heat value of one pound of total combustible (fixed carbon plus volatile matter) is, however, about the same as for Illinois coals. The coals of Iowa contain less moisture, about the same per cent of ash and about the same ratio of fixed carbon and volatile matter as does North Dakota lignite. The heat value per pound of combustible is higher because the volatile matter in the lignite does not contain so many heat units per pound.

The best argument for the use of Iowa coal in house heating work in this state is the low cost per ton on account of the short distance to the mine. When a furnace is developed that will burn a greater per cent of the volatile gases, this advantage will be increased accordingly.

The fact that a large per cent of the rich volatile combustible is wasted and the waste accompanied by large and unpleasant quantities of smoke is one of the big arguments for a better treatment of Iowa coals. If a satisfactory process could be invented or developed, whereby the volatile hydro-carbons would be converted into a liquid or gaseous fuel, and whereby the resulting coke would be used for such purposes as house heating, an enormous increase in the value of such soft coals would result. The value per B. T. U. is now nearly ten times as much in a liquid fuel like gasoline as in Iowa coal and a gas can be burned with much more convenience and efficiency. The coke would of course have a high percentage of ash and would be more difficult to kindle; but those are not serious faults in many uses.

Washing coal also helps to a certain extent in removing non-combustible elements and in making it cleaner to handle.

Article 14. Foreign Fuels. Considerable variation in grade, price per ton and analysis was observed with the Illinois coals. Little Jack was found to be the most pleasant to handle and gave the lowest evaporative cost, although Illinois pea-coal was nearly as low. As with Iowa coals, considerable smoke, soot, dirt and dust were encountered. The sulfur content of Illinois coals is usually lower but the cheap grades of Illinois coal form as much or more clinker than the Iowa lump coals.

The Kentucky and Tennessee coals are very quick to fire but fuse together into masses in the furnace. The former is of a tough blocky structure, exudes much tarry matter when heated and becomes quite plastic before being entirely coked.

Tennessee Smokeless is of a loose granular structure and breaks up if handled much. Its composition appears to vary greatly. A sample of a different shipment from that actually tested but selling at the same price was analyzed at the Station and yielded 79.0 per cent fixed carbon and only 4.2 per cent of ash with a heat value of 15,130 B. T. U. per pound of dry coal. Had this coal of less ash composition been used an evaporation cost of less than 37 cents as against 41.6 cents with that burned in the actual test should have been obtained. Tennessee Smokeless and Solvay coke evaporated more water per pound of fuel than any other fuels tested, including anthracite. No appreciable amount of clinker was formed with either the Kentucky or Tennessee coals.

The proximate analysis of Tennessee Smokeless is very similar to that of Pocahontas coal which sells at Ames at about 50 cents more per ton.

The big variation in heat values of fuels as purchased, noticed especially in the case of Tennessee Smokeless, is a very pertinent argument for the sale of fuels on the B. T. U. basis. The cost per B. T. U. in the better sample was only 88% of the cost in the lower grade. It is not practicable to have each lot sold to the customer analyzed, but each car load coming to the dealer might have its heat value determined.

The cokes contain practically no moisture, very little volatile matter and about as much ash as the soft coals, except petroleum coke which has about 10% of volatile matter and about 2% ash. Anthracite lies between the better soft coals and coke in respect to fixed carbon and volatile matter and usually contains less ash than either. The cokes and anthracite do not cake, form practically no clinker, and yield a minimum of dirt, obnoxious gases, smoke and soot. Solvay coke is even in appearance and harder than gas-house coke, which is uneven in appearance and structure. Foundry coke has a more whitish lustre than either of the above two. All are somewhat porous. Petroleum coke is the residue from petroleum distillation, has a very black shiny appearance and is more porous and more liable to crumble than any of the other cokes.

VI. GENERAL DISCUSSION.

Article 15. Tests and Results. *1. Varieties of Tests.*—Two general kinds of tests were employed, designated as "short firing" and "long firing." For "short firing" tests the fire was fed about every two or three hours. For "long firing" tests enough fuel was fired at the beginning to last through the entire test. The object was to learn the efficiency secured by (1) keeping the fire at a low and fairly constant level, and

that secured by (2) the usual practice of nearly filling the furnace and allowing a gradual lowering of the fuel level toward the grate. The fuel economy was usually found to be better under the latter conditions. An equal number of each kind of tests was not made upon all of the fuels listed in tables I and II; hence the figures presented there are not quite fair to all. On that account the number of each kind of firing is included in the same tables.

Special tests were made to study the effect upon efficiency of mixing of fuels, size of fuel, depth of fuel bed, capacity developed and damper openings. These special tests are all discussed later.

2. Length of tests.—The aim was to make each general test approximately 8 hours long. For most short firing tests the time was fairly easy to fix, while in the long firing tests an obstacle was encountered on account of inability to estimate beforehand the evaporative power of the fuel employed. The general tests on cokes and coals actually varied in length from 5.5 hours to 9.67 hours. The test on peat was 3.33 hours long. Some of the special tests were even shorter.

No attempt was made to determine the effect length of test had upon efficiency. At Urbana the lower efficiencies were had with the shorter tests. This was thought to be due partly to more inefficient burning of the first fire. The difference was not so marked between 16-hour and 24-hour tests as between 8-hour and 16-hour tests. There is no doubt that longer tests reduce the per cent of errors of observation. Longer tests would have reduced the per cent of loss in grate droppings at Ames.

3. Mixtures of fuels.—Three tests were made burning a coke together with an Iowa soft coal to learn if the volatile matter in the latter could be better utilized because of the presence of more fixed carbon. Test No. 10 was made with 2 pounds of Saylor coal to 1 pound of gas-house coke, well mixed before firing. For the other two tests equal weights of Boone coal and Solvay coke were used. In No. 25 the Boone coal was fired first with the coke directly on top. In No. 26 the two were well mixed before firing.

In all three trials, practically the same evaporative power was realized that occurred when the coke and coal were burned separately.

Following are the figures leading to the above deduction.

Test No.	10	25	26
Fuel	Saylor—2/3 Gas-house coke—1/3	Boone—1/2 Solvay coke—1/2	Boone—1/2 Solvay coke—1/2

Kind of Firing........	Short	Long	Long
Equiv. Evap. (212°F.) per lb. Fuel as Fired	6.21 lb.......	6.00 lb......	6.03 lb.

Equivalent average evaporation (212°F.) for 2/3 lb. Saylor coal and 1/3 lb. gas-house coke derived from separate tests No. 2 and 4 on Saylor coal and Nos. 8 and 11 on gas-house coke........................... 6.07 lb.
Difference by test No. 10.............................. 0.14 lb.
Equivalent average evaporation (212°F.) for 1/2 lb. Boone coal and 1/2 lb. Solvay coke derived from test No. 24 on Boone and tests No. 22 and 23 on Solvay coke .... 6.11 lb.
Difference by test No. 25.............................. 0.11 lb.
Difference by test No. 26.............................. 0.08 lb.

4. *Type and Size of Boiler.*—Experiments upon more than one type of heating plant would have added value to the results obtained. Data would have been especially interesting on hot water heaters where the heating surface is usually cooler than in the steam boiler and on hot air furnaces where the heating surface is often hotter than in the boiler. Of the two types of steam boilers used at Urbana, one gave a higher efficiency with all fuels tested, thus supporting the idea that nearly the same order of fuel efficiencies obtains in boilers of different types. The difference was much more marked, however, in the case of Pocahontas coal, the ratio of its efficiency in the two boilers being about 4 to 5. In fact, Boiler D_1, which is of the vertical type, gave a lower efficiency with Pocahontas coal than with Illinois soft coals. With Boiler D_2, which is of the horizontal type, the reverse was true. Since the analysis of Tennessee Smokeless, tested at Ames, is similar to that of Pocahontas coal, it may be that the Tennessee coal, which showed up so well in the horizontal boiler at Ames, would not do so well in a vertical boiler or furnace.

The rated capacity of the boiler used at Ames, 1,350 square feet of radiation, is something like two or three times that usually installed for an 8-room house in this climate. While the size of unit is one of the factors affecting efficiency, yet it is believed that the smaller unit such as is required for an 8-room house will have nearly as high efficiency. or at least the same order of fuel efficiencies, other conditions being similar. Also, the results ought not to be much different for larger units of the same type.

5. *Comparison with power boilers.*—As might be expected, lower efficiencies are obtained in a house heating boiler than

in a power boiler. The ratio is something like from 80% to 95% as between the house heating boiler herein described and power boilers of 100 and 200 horse power capacities used in different parts of the State. The difference is due perhaps to a number of things, among which might be the larger size of the power boiler, a higher temperature of combustion in the power boiler, and a smaller heating surface per unit of evaporation in the house heating boiler, resulting in a higher temperature of waste chimney gases. A low furnace temperature may mean poor combustion of the volatile gases and a high temperature of chimney gases means more heat carried out the stack.

6. *Rate of Evaporation.*—For the general tests it was the aim in operating to regulate evaporation to the equivalent evaporation of 200 pounds of water from and at 212° F. per hour which is very nearly 60% of the boiler's rated capacity. The actual average equivalent evaporation for the tests on cokes and coals varied from 170 to 227 or from 50.3% to 67.3% of the rated capacity. Most of the tests however were between the limits of 55% and 65% of the rating.

At 50% of the rated capacity the equivalent evaporation from and at 212° F. is 2.15 lb. per hour per square foot of boiler heating surface, and at 60% it is 2.58 lb. 2.58 lb. corresponds to 13.4 sq. ft. of heating surface per boiler horse power.

It is well known among heating engineers that for this climate and for local fuels, heating boilers and furnaces are highly over rated. This partly explains why it is necessary to install a boiler or heater of a rating higher than the actual capacity required to be developed. Another reason will be discussed in the next paragraph. There is no valid reason why a square foot of heating surface in a house heating boiler should be given a higher rating of evaporation than in a power boiler unless it be that fuel economy is sacrificed for low first cost and a small boiler space.

7. *Capacity with different fuels.*—Another point which should influence judgment on the capacity of a furnace or boiler chosen is the kind of fuel to be used. Table IV on page 21 gives the comparative lengths of life of full charges of the various fuels. A great difference exists between anthracite and Iowa coals. The over rating of heating boilers is now further explained when it is stated that the maker's rating is based upon the evaporation that can be maintained for 8 hours with 80% of a charge of *anthracite* filling the furnace to the level of the center of the fire door. The other 20% is considered as a rekindling charge.

There are also times in severe weather when the full estimated supply of heat will not be sufficient. Of course it must be expected that the furnace will be over worked at times, but all things must be considered.

Taking into account then the high evaporative rating, the burning of soft coals, and the excess heat required at times, it will usually be found advisable to install a boiler rated at least twice the capacity actually required under ordinary circumstances.

8. *Operating conditions.*—Outside influences such as would affect conditions did not change much from test to test. The temperature of boiler room air ranged from 58° F. in winter to 92° F. in summer. The boiler feed water ranged in temperature from 47° F. to 72° F. More soot may have been present in the chimney and in the pipe leading to it during the last tests, but the draft readings, as the tests went on, did not indicate any noticeable effect from such cause.

9. *Difficulty of maintaining constant conditions and of securing equitable observations.*—The efficiency reached hinges more or less upon constancy of conditions. In these tests the feed water entered through a hand regulated valve from a cold water main. There was no objection to the cold water if its entrance could have been kept at a constant rate of flow. But that was not quite possible and the valve opening had to be changed from time to time to keep the water in the boiler at the proper level. A greater influx of cold water would lower the boiler pressure which would in turn actuate the damper regulator to admit more air to the fire. The fire would then burn up, increasing the temperature of the waste gases, and the impetus thus gained would raise the boiler pressure to above normal before the fire could be checked down again. Such fluctuations do not make for the best economical results. In some cases this effect was more marked than in others.

Those fuels having the most tendency to cake and clinker were accordingly most inclined to burn holes or to form dead spots in the fire. From one standpoint it might seem just to poke and level all fuels at the same interval of time. Or it might seem just to keep one fire as free from holes and dead spots as another. The actual policy followed lay between these two. All fires were fixed as the operator saw fit, and no record was made of the time of attention. Poking and leveling were not resorted to so often however that effect of holes and dead spots upon fuel economy was completely obliterated.

Difficulty of collecting accurately representative samples of flue gas is always prominent. Composition of the gases is likely to vary in different parts of the stack or flue from which they are drawn. Without a recording indicator it is practically im-

possible to make analyses as often as other readings are taken. And analyses as far apart as one hour may not represent the average. Difficulties experienced with continuous samplers or collectors were in getting the large amount of water required in such a condition that it would have no effect upon the composition of gas, and in drawing a fair sample of the gas so collected into the analyzing apparatus. Agitation of the gas before being drawn from the sampler resulted in a considerable difference of composition as analyzed.

The greatest danger of unavoidably inaccurate observation lay, it is believed, in starting and stopping the tests. The alternate method was employed in which the end of test was determined when it was estimated that the same value of fuel lay upon the grate as at the start of the test. With the small amounts burned in an 8-hour test, an error of a few pounds would make an appreciable percentage of error in the calculated results.

Unconsumed carbon in ash and refuse, caused partly by fuel falling through the grate from the fresh fire, was always greater than would likely be obtained in actual practice. In actual practice there is usually a layer of nearly carbon free ash on the grates which prevents the fuel from dropping through. Also it seemed best to allow the fuel remaining at the end of test to burn down before shaking the grates and weighing up the ash and refuse. Some fuels such as coke would not burn down so well, and while a correction was made, yet absolute accuracy could never be depended upon. Had the grates been shaken at the end of test, too much unconsumed fuel might have gone through or the fuel left upon the grates might have contained ash that should have been included in the weight of ash and refuse. The so-called standard method by which the test begins with a new fire and ends with collection and analysis of the entire contents of both ash pit and fire box, also has objections. Conditions during the first minutes of test are not representative of the test as it should be, and handling of the fuel and ash at the end of test is inconvenient.

10. Variations.—The most noticeable variations in results between two or more tests of the same fuel are in the case of Boone coal and gas-house coke. The low efficiency of boiler and grate (31.5%) in short firing test No. 24 with Boone coal is thought to be due to the poor condition of the lot from which it was taken. The proximate and calorific analyses did not differ much from the others. This coal had been in storage for several months. It was broken and small in size, and from its general appearance one might think it had deteriorated greatly. This was one of the few tests in which CO was analyzed for,

and resulted in finding an average of 1.5% CO by volume, showing where a part of the large waste went to. The rapid burning down of this coal in the furnace with the usual rate of evaporation was surprisingly noticeable. The average boiler and grate efficiency of three short firing tests on two other lots of Boone coal was 46.8%.

Of the two short firing tests on gas-house coke, No. 8 resulted in 65.8%, and No. 11 in 55.5% efficiency. Most of this difference is accounted for by a higher temperature and a greater excess of oxygen in the flue gases from the latter test. The calculated per cent of heat carried away by stack gases was 23.7% while in test No. 8 it was only 15.9%. The personnel of observers was changed between these two tests and may have had something to do with the difference in results.

Test No. 6 on foundry coke is not considered conclusive, since the efficiency is low and the per cent of heat unaccounted for is suspiciously high for a fuel so high in fixed carbon.

The only fuel giving a better efficiency with short than with long firing was Ogden lump coal. This may have been due to its natural composition or to operating conditions.

The apparent fact that soft coals high in fixed carbon such as Little Jack and Tennessee Smokeless have a better efficiency than anthracite may be due to the fact that anthracite does not produce a flame long enough for the best result. It is also true that an 8-hour charge of anthracite, at the capacity employed, did not bring the fuel level so high in the furnace as with the lighter coals. See Article 19.

Article 16. Probable Errors. Errors affecting fuel analysis were the ones most likely to be introduced and were probably greatest in sampling. The heat values obtained are not supposed to be in error by more than 2 or 3 per cent. The process of analysis in itself is much more accurate. The most difficulty encountered in checking was with the analysis of peat, the moisture content of which is quite unstable.

The calculated composition of ash and refuse should be within 5% of the actual, and is considered better than an actual analysis because of the difficulty of securing a fair sample.

Thermometer readings were taken to the nearest degree. The pyrometer readings of flue temperatures may be off as much as 10 or 20 degrees, F.

Boiler and barometric pressures were read closer than was actually necessary for calculating the quality of steam to within one-tenth of one per cent.

The recorded analyses of CO_2 and oxygen in the flue gas may be as much as 2% from the true averages in some tests.

The largest possible error of all observations was in determining the time when as much heat value was left in the fuel

bed as was present at the start of test. In extreme cases the error of fuel weight might have been as much as 10 pounds. With a total fuel weight of 200 pounds, 10 pounds would mean an error of 5% and with a fuel weight of 300 pounds the per cent of error would be 3.33.

The recorded weights of fuel, ash and refuse, and of evaporation should be within 1% of the actual.

An idea of the accuracy of evaporative performance, which involves both evaporation and estimating end of test, may be gained by quoting here figures from Article 21 on Amount of Fuel Charge and Efficiency. Both long and short firing tests were made upon 11 different fuels. The average difference between the two methods in boiler and grate efficiency was 2.7% in favor of the long firing. The difference varied from 2.9% in favor of the short firing to 5.7% in favor of long firing. It is believed that the variations of these differences from the average is due as much if not more to the nature of the fuel rather than to errors of observation.

Practically all calculations were made with the slide rule and are usually accurate within about one half or one quarter of one per cent of the resulting quantity.

Ultimate analyses of the fuel were not made and the calculated per cent of heat carried away in the flue gases was based upon all carbon and no hydrogen in the combustible. The hydrogen actually present in Iowa coals would seldom increase this item by more than 2.5% of the total heat value of the original fuel.

Article 17. Comparisons with Other Tests. As mentioned in the introduction, some tests were made upon the boiler at Ames early in 1911 for thesis work. One 8-hour test was made upon each of Boone, Saylor, and Colfax coals. Following in table V are some of the more important quantities taken from the thesis reports.

A most superficial comparison of Tables V and VI reveals a greatly lowered fuel economy under unfavorable conditions. From table V it appears that among the causes of poor results might be included too frequent disturbances of the fire, a too high rate of evaporation with the draft available, too low an excess of oxygen, and coals which had deteriorated or which had been broken up into pieces too small to burn properly. Much of the rich volatile combustible was distilled off without burning as indicated by the low total per cents of CO_2 and oxygen and by the high per cents of heat unaccounted for. Soot collected so rapidly that it was found necessary to clean the flues about every two hours in order to keep up the normal steam pressure. The pipe leading from the furnace to the chimney and made up of horizontal and vertical sections, was

TABLE V.

THESIS TESTS—BOONE, SAYLOR AND COLFAX COALS.

Fuel	Boone	Saylor	Colfax
Proximate Analysis			
Moisture, %	8.64	8.88	5.89
Volatile Matter, %	31.57	31.57	34.98
Fixed Carbon, %	45.44	47.68	46.73
Ash, %	14.35	11.87	12.40
Calorific Analysis			
B.T.U. per pound of fuel as fired	10,710	11,450	11,390
Boiler Gauge Pressure	4.54	5.12	5.17
Draft in Flue, ins. water	0.076	0.098	0.117
Draft in Furnace, ins. water	0.010	0.023	0.010
Temperature of Gases from Boiler, °F	600	600	600
Flue Gas, CO_2, by volume	11.2%	11.6%	12.2%
Flue Gas, Oxygen, by volume	3.4%	2.4%	1.8%
Flue Gas, Nitrogen, by volume	85.4%	86.0%	86.0%
Total Fuel Fired, lbs.	506	573	668
Ash and Refuse, total lbs.	33.5	29	25.2
Equiv. Evap. (212 °F.) per pound fuel as fired	3.47lb	3.74lb	3.81lb
Boiler and Grate Efficiency	39.4%	31.7%	32.5%
Cost of Coal per Ton	\$3.50	\$3.50	\$3.25
Cost of 1000lb Equiv. Evap. (212 °F)	50.3c	46.9c	42.6c
Per Cent of Rating Developed	65.1	79.2	94.4
Boiler Heat Balance			
Heating and Evaporating Water	39.40%	31.70%	32.50%
Heating Flue Gases	10.83	11.26	10.54
Evaporating Moisture in Coal	1.04	1.00	0.64
Grate Losses	1.60	0.73	0.51
Unaccounted for	47.13	55.31	55.78
Total	100.00%	100.00%	100.00%

The most noticeable differences between the above results and those obtained later by the Station tests on the same fuels are apparent from an examination of Table VI, which follows.

TABLE VI.

STATION TESTS—BOONE, SAYLOR AND COLFAX COALS.

Fuel	Boone	Saylor	Colfax
Number of Test	4	2	32
Draft in Flue, ins. water	0.122	0.123	0.130
Draft in Furnace, ins. water	0.087	0.062	0.100
Temperature of Gases from Boiler, °F	653	663	630
Equiv. Evap. (212 °F.) per pound fuel as Fired	5.06lb	5.22lb	5.01lb
Per Cent of Rating Developed	61.2	54.4	61.4
Boiler and Grate Efficiency	46.8%	43.5%	42.0%
Boiler Heat Balance			
Heating and Evaporating Water	46.8%	43.5%	42.0%
Heating Flue Gases	19.9	19.4	13.7
Evaporating Moisture in Coal	1.4	1.3	0.9
Grate Losses	2.7	7.2	9.0
Unaccounted for	29.2	28.6	34.4
Total	100.0%	100.0%	100.0%

taken down and cleaned before starting the Station tests. More than half its cross section was found to be filled with soot. After cleaning it was erected in an inclined position as shown in figure 10, page 53. By referring to table V a great difference will be apparent between the draft just outside the furnace and that in the furnace just over the fire, which might indicate the presence of some obstruction between these two points which did not exist when the Station tests were made.

Firing for the tests in table V was much more frequent than in any of the Station tests. The fuel was fired one shovel-full at a time just often enough to keep the fire at a constant level. The grates were shaken and the slicing bar used much more also. The frequent agitation of the fire undoubtedly had some effect upon the efficiency. Boiler logs indicate that flue temperatures were estimated rather than read since every 20 minute record is at 600° F. Since the three fuels were all nearly of the same class, the temperatures would no doubt be higher for the tests with higher rates of evaporation.

Tests at the Illinois Engineering Experiment Station, Urbana, Illinois, with 7 fuels in 2 types of boilers resulted in the same general order of fuel efficiencies as did those at Ames,—cokes coming highest, anthracite second and soft coals lowest.

The two types of boilers are designated as D_1 and D_2. D_1 is a vertical boiler, rated at 800 sq. ft. of radiating surface. D_2 is a horizontal sectional boiler rated at 1,075 sq. ft. of radiating surface. Better efficiencies were secured with D_2 than with D_1. Three of the fuels tested at Ames were also tried at Urbana—anthracite, gas-house coke and Solvay coke. The efficiency obtained with these three fuels at Ames are about the same as the averages of the 8-hour, 16-hour and 24-hour tests on the same fuels in boiler D_2 at Urbana. Boiler heat balances are not included in the Illinois bulletin, so that comparison on such basis is not so easily made.

The standard method of starting and stopping tests was used at Urbana. The average per cent of rated capacity developed was about 65. The evaporative costs were of course lower than at Ames on account of the lower ton costs of good grades of fuel in Illinois.

Anthracite, coke and Pocahontas coal were fired by the spreading method. Illinois soft coals were fired in a way approaching the coking method. "In all tests made with Boiler D_1, 75 lb. of fuel were fired at one time, and in all tests made with D_2, 105 lb. of fuel were fired at one time."

The average plant efficiencies of each fuel on each boiler are plotted on figure 3, page 36. Other references to the Illinois tests will be found in Article 15, on Tests and Results, pages 24 and 25, and in Article 19 on Fixed Carbon and Efficiency.

VII. GENERAL CONDITIONS RELATED TO EFFICIENCY WITH GRAPHICAL REPRESENTATIONS.

Article 18. Significance of Readings and Results. While errors due to unfair conditions are always liable to creep in and spoil some of the effects of finer readings, yet much prac-

tical knowledge of actual working conditions can be gained by a study of seemingly theoretical observations.

Flue gas analysis requires some study for a true interpretation. Air contains by volume about 79% nitrogen and about 21% oxygen. When burning carbon to CO_2 (carbon dioxide) the sum of CO_2 and oxygen should also equal 21%. When the sum is less than 21%, CO (carbon monoxide) should be present. If there is hydrogen in the fuel, H_2O, or steam, will be formed by its combustion. The steam will be condensed before the gas is analyzed, and less than 21% of CO_2 and oxygen will result. If combustion is not perfect there will be a still lower total of CO_2 and oxygen. A lower total then with one fuel than with another does not necessarily mean poorer combustion. But in general, a very low total per cent of CO_2 and oxygen in the flue gases indicates that some CO or hydrocarbon gas or both, are escaping unburnt.

The boiler heat balance proves of much service in furnishing an idea of how the heat value of the fuel is distributed among useful heating and different losses. The per cent of heat loss calculated for the flue gases is not exactly accurate because of the hydrogen content in the volatile matter of soft coals, the heat carried out by the products of combustion from one pound of hydrogen being much greater than the corresponding amount for one pound of carbon. The per cent of heat unaccounted for is in some respects misleading because it includes the variable unknown errors as well as radiation losses and the heat in unconsumed fuel and gases. Notwithstanding these faults, the boiler heat balance is thought to be well worth using.

Special tests were made in order to study the effects of size of fuel and rate of evaporation upon efficiency, and to study also the effects of various damper positions.

Article 19. Fixed Carbon and Efficiency. Other things being equal the ratio of fixed carbon to volatile matter appears to have a very direct effect upon the efficiency. The "other things" are however not easy to control or estimate. The size, structure, freshness and percentages of chemical constituents, as well as operating conditions are liable to be different for every fuel tried. But numerous and careful tests made by U. S. Government and State experimentalists prove the assertion made in the first sentence of this paragraph. This subject is discussed and illustrated by means of diagrams on pages 232-236 and pages 253-262 of Bulletin 23, U. S. Bureau of Mines on "Steaming Tests of Coals." It is also discussed and illustrated in the Illinois bulletin referred to in the Introduction to this bulletin.

Figure 2 is a diagram with the average boiler and grate efficiency of each fuel plotted against the average per cent of

heat in the fixed carbon. This classification according to the per cent of total heat value contained in the fixed carbon is one which the writers have never seen used before, and is one which they believe has certain advantages over other classifications. It is more simple than the "carbon-hydrogen ratio" in that it requires no ultimate analysis. It appears to be more just than the classification based upon the weights of fixed carbon and volatile matter, because a certain weight of volatile matter may vary greatly in heat value, and efficiency is the ratio between evaporation and *heat value* of the combustible—not between evaporation and *weight* of the combustible. Data from which figure 2 is made will be found in table VII, page 34, Fixed Carbon and Efficiency.

TABLE VII.

FIXED CARBON AND AVERAGE EFFICIENCY.

No. of fuel	Name of fuel	Weight of fixed carbon in fuel as fired	Part of total heat in fixed carbon	Efficiency		
				By test, boiler and grate	By Formula 1	By Formula 2
		%	%	%	%	%
1	Boone	39.8	54.5	43.6	46	
2	Buxton	43.7	59.8	51.5	50.5	
3	Centerville	46.5	54.2	44.6	46	
4	Colfax	42.2	53.1	43.4	45	
5	Ogden	41.0	51.4	44.6	43.5	
6	Saylor	42.5	52.5	43.6	44.5	
7	Empire lump	44.1	55.4	49.0	47	
8	Empire nut	45.4	57.7	46.9	49	
9	Little Jack	54.8	65.8	55.9	55.5	
10	Ill. Mine Run	41.5	56.9	51.5	48	
11	Ill. Pea-coal	43.8	56.1	42.8	47.5	
12	Ken. Red Torch	56.2	55.1	42.8	46.5	
13	Tenn. Smokeless	68.3	75.3	64.2	63	
14	Foundry Coke	84.0	96.5	52.3		62
15	Gas-house Coke	82.3	97.5	60.6		63
16	Petroleum Coke	86.1	84.0	51.9		52
17	Solvay Coke	86.6	97.5	65.6		63
18	Egg Anthracite	86.3	91.2	54.8		58
19	Pea-anthracite	79.5	88.5	56.6		55.5
20	Iowa Peat	12.5	51.8	43.2	44	

[1]Efficiency=.625—.8(.75—x), with x between .50 and .75.
[2]Efficiency=.650—.8(1.00—x), with x between .80 and 1.00.

The writers have taken the liberty of averaging the plant efficiencies of each fuel with each boiler as tested at Urbana and have plotted them in figure 3 against per cent of heat in fixed carbon and against per cent of weight of fixed carbon.

One classification comes about as near making definite curves as the other.

Of the greater variety of fuels tested at Ames, however, the classification on weight of fixed carbon of such fuels as peat

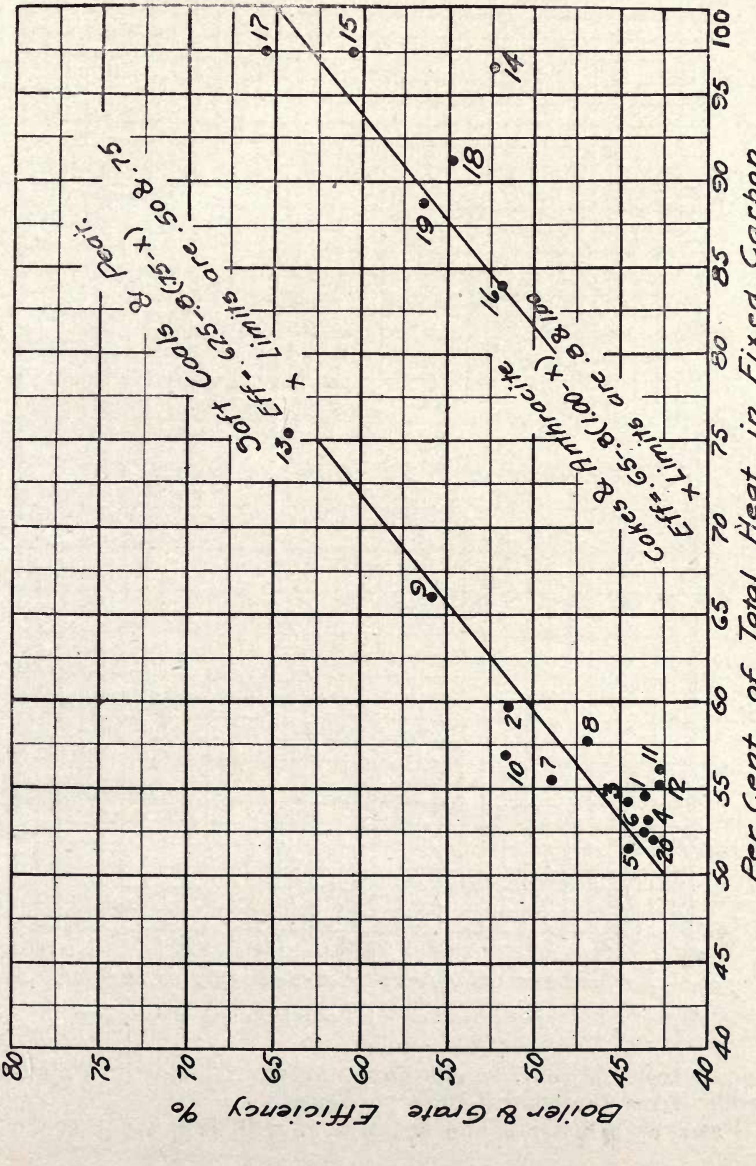

Fig. 2.—Relation between Fixed Carbon in Fuel and Efficiency—Ames Tests.

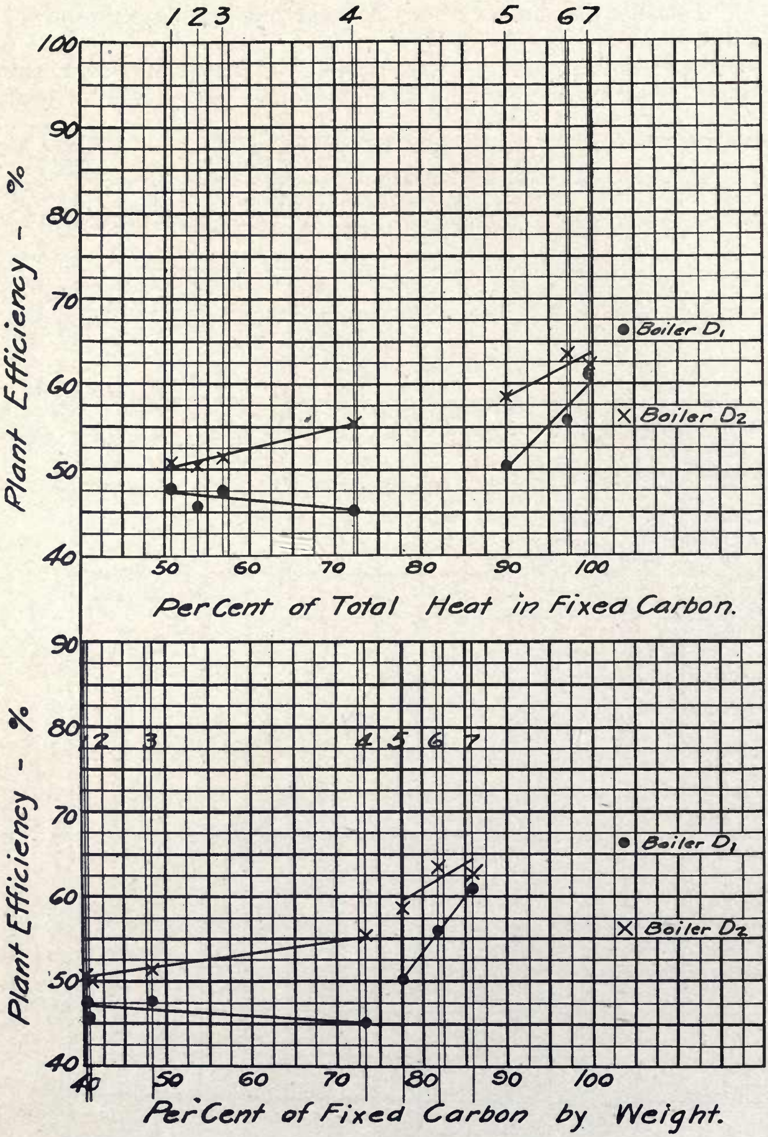

Fig. 3 —Relation between Fixed Carbon in Fuel and Efficiency—Illinois Tests

and petroleum coke would have thrown their points much farther from the central lines on figure 2.

From both figure 2 and figure 3, it will be noted that for

all three types of boilers, the fuels divide themselves into two groups with soft coals in one and anthracite and the cokes in the other. No conclusive reason can be given for this, although it is possible that the longer flame resulting from the burning of soft coals is conducive to better efficiency, and thus accounts to a certain extent for the natural grouping.

It will also be noted that the change in efficiency is different for each type of boiler. For the boiler tested at Ames the central line or curve representing the soft coals and peat has the formula,

$$\text{Efficiency} = .625 - .8(.75 - x),$$

when x lies between the limits of 50% and 75% and represents the per cent of heat value in the fixed carbon. The line for anthracite and coke has the formula,

$$\text{Efficiency} = .65 - .8(1.00 - x),$$

where x lies between the limits of 80% and 100%.

The per cent of total heat in the fixed carbon is arrived at by multiplying the per cent of weight of fixed carbon by 14,500 B. T. U. and then dividing by the total heat value of one pound of fuel.

The fact that fuels high in volatile combustible give lower efficiencies is partly explained by the theory that the hydro-carbons are distilled into gases which escape before the furnace temperature is high enough to bring about their complete combustion. In connection with the above statement is the theory that the hydro-carbons, which are driven off as oily vapors, cannot come into sufficiently intimate contact with the oxygen of the air to produce good combustion. A particle of vapor may be completely surrounded by live air at a high temperature, and yet only the lighter elements of the outer layer of that particle may be consumed. The central part of the particle will then carry a greater per cent of carbon and will pass out of the combustion chamber unconsumed. Such particles as are made up almost entirely of carbon appear as visible smoke.

Fixed carbon on the other hand cannot escape in the form of a gas until it has been burned into carbon monoxide (CO) or carbon dioxide (CO_2). If the air supply is insufficient, some carbon will be burned only to CO which gas represents a utilized heat of only about one-third as much as does CO_2.

Visible smoke contains finely divided particles of carbon in the solid state, escaping with the gases, but does not usually amount to an appreciable loss of heat value. Its presence however does signify that considerable heat is escaping in the form of colorless and unburnt combustible gases.

The presence of unburnt combustible gases in the stack may also be detected by a low total per cent of CO_2 and oxygen

from the flue gas analysis, as explained in article 18, Significance of Readings and Results. Figure 4, page 39, illustrates roughly this statement. Each point on the diagram represents the average for each fuel of all the general tests on that fuel. An exception is made to this grouping in the case of Boone coal because the test on one lot was so much different from those on the two other lots of the same fuel. The points are plotted between the total per cents of CO_2 and oxygen, and the per cent of heat unaccounted for. Per cent of heat unaccounted for is used rather than boiler efficiency because it is supposed to better reveal the per cent of heat escaping in the form of unconsumed gases. It is believed that the points would group themselves in an area of much less width were it possible to isolate the two quantities involved from the effect of a multitude of dissimilar circumstances. Table VIII, page 38, gives the data corresponding to figure 4.

TABLE VIII.

ANALYSIS OF FLUE GAS—AVERAGES.

Fuel			Dry flue gas by volume				
No.	Name	Part of total heat in volatile combustible	CO_2	Oxygen	CO_2 plus oxygen	Nitrogen and unburnt fuel gases	Part of total heat in fuel fired unaccounted for
		%	%	%	%	%	%
1	Boone[1]	53.8	9.4	9.3	18.7	81.3	27.6
1	Boone[2]	55.7	10.5	5.7	16.2	83.8	43.5
1	Boone[3]	56.0	10.3	6.4	16.7	83.3	35.6
2	Buxton	40.2	12.9	5.9	18.8	81.2	28.0
3	Centerville	45.8	12.8	6.1	18.9	81.1	33.3
4	Colfax	46.9	12.8	5.5	18.3	81.7	32.7
5	Ogden	48.6	13.7	4.8	18.5	81.5	36.8
6	Saylor	47.5	10.6	7.4	18.0	82.0	30.9
7	Empire lump	44.6	13.5	4.2	17.7	82.3	30.7
8	Empire nut	42.3	11.8	5.4	17.2	82.8	32.6
9	Little Jack	34.2	11.9	5.8	17.7	82.3	22.7
10	Ill. Mine Run	43.1	10.6	7.6	18.2	81.8	20.5
11	Ill. Pea-coal	43.9	13.4	4.8	18.2	81.8	39.0
12	Ken. Red Torch	44.9	12.3	5.7	18.0	82.0	31.7
13	Tenn. Smokeless	24.7	14.4	4.9	19.3	80.7	21.0
14	Foundry Coke	3.5	9.2	10.7	19.9	80.1	25.1
15	Gas-house Coke	2.5	8.6	11.2	19.8	80.2	12.8
16	Petroleum Coke	16.0	14.0	4.9	18.9	81.1	26.8
17	Solvay Coke	2.5	11.9	6.7	18.6	81.4	10.5
18	Egg Anthracite	8.8	11.9	8.4	20.3	79.7	18.7
19	Pea-anthracite	11.5	7.2	12.3	19.5	80.5	13.4
20	Iowa Peat	48.2	13.9	5.1	19.0	81.0	19.0

[1]Tests 3 and 4.
[2]Test 24.
[3]Tests 27 and 28.

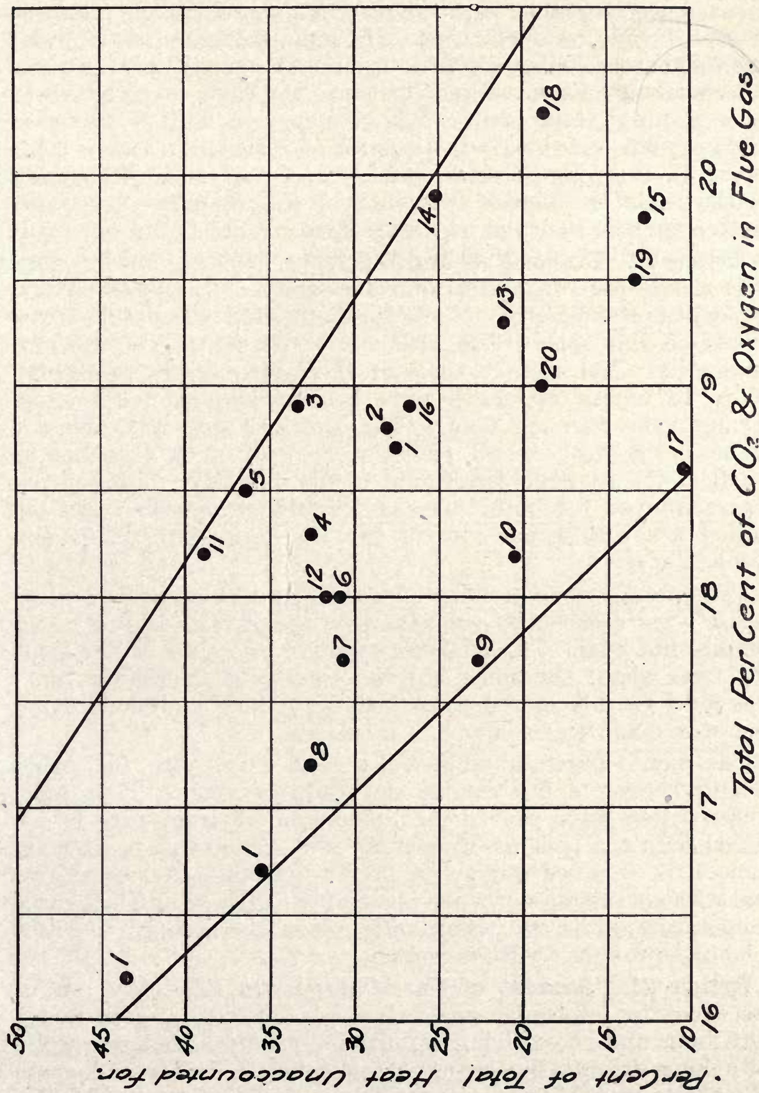

Fig. 4.—Relation between Composition of Flue Gas and Heat Unaccounted for

Such classification of fuels as illustrated in figures 2 and 3 suggests a plan whereby every operator of a house heating plant could determine for himself very nearly what the comparative cost of various fuels would be without a test on any of them. All that would be necessary for calculating the cost

would be the characteristic of the type and size of boiler or furnace used together with the proximate and calorific analysis of each fuel to be considered. The manufacturers of the heating furnace or boiler could determine for each type, its characteristics in regard to fixed carbon in the fuel. Each operator of a heating plant could then be supplied with a curve or table of data on the characteristics of his plant. Then if his dealer in fuels supplies him with prices per ton and analyses of the fuels he handles, it would be a comparatively simple matter for the operator to figure heating costs.

Article 20. Size of Fuel and Efficiency. Special observations were made, tests 46 and 47, for the study of the effect of size of coal upon efficiency. Fuels for both tests were taken from the same shipment of Buxton coal which was quite uniform in quality. For test 46 some of the larger lumps measuring 16 to 18 inches in length were broken just enough to pass through the furnace door. The average size was about 8 inches. For test 47 all pieces were broken to 4 inches or smaller, the average size being about 3 inches. Long firing was employed for both. The boiler and grate efficiencies obtained are 53.3% and 49.8% for the large and small size respectively.

The average of tests 31 and 34 on Empire lump coal resulted in 2.1% more efficiency than the average of tests 19 and 20 on Empire nut coal. The analyses of these two sizes of the same coal was about the same but the smaller size (Empire nut) was more freshly mined when tested. A long and short firing test was made on each.

The same increased efficiencies with large size fuel were noted wherever a fair comparison could be made. Tests upon power boilers have proved that maximum efficiency may be obtained with coal smaller than lump size. However, in such instances the fuel bed was not so deep and could better carry fine coal without cutting down the air supply. Also the high furnace temperature under the power boiler was more conducive to better combustion of the hydro-carbons.

Article 21. Amount of Fuel Charge and Efficiency. With the exception of Ogden coal, all of the 11 fuels, tested under both long and short firing conditions, produced better results with long firing. The average difference in boiler and grate efficiencies was 2.7% of the total heat value of the fuel. The variation was from 0.3% with Saylor coal to 5.7% with Centerville lump coal. The opposite difference with Ogden coal was 2.9%. Short firing or small charge tests usually resulted in a greater per cent of heat carried out by the flue gases or unaccounted for, indicating that frequent firing of small charges

is either wasteful of heat actually generated or is unfavorable to good combustion.

Article 22. Depth of Fuel Bed and Efficiency. The average depth of fuel bed depends upon the style of firing and amount of fuel charge. A special test, 7 hours in length, was made to determine the effect of depth of fuel bed upon flue gas temperature and composition. The principal log records are given in table IX, page 41 and plotted in figure 5, page 42. Each observation plotted was made after conditions had become quite constant. After each such observation the fire was cleaned or replenished with fresh fuel so that all conditions imposed except depth of fuel bed should be approximately the same for the next result. A mixture of soft coals was used and the rate of evaporation was about 60% of the rated capacity of the boiler.

TABLE IX.

DEPTH OF FUEL BED AND FLUE GAS.

Time	Depth of fuel bed	Draft in flue, ins water	Flue Gas					
			Temperature	By Volume			Sensible heat as part of fuel value	
				CO_2	Oxygen	CO_2 plus oxygen		
	ins.		°F.	%	%	%	%	
9:10 AM	Fire kindled.							Building up period.
9:40 AM	Fuel fired (100 lbs.)							
10:15 AM	3.0	.13	690	12.0	5.5	17.5	17.1	
10:20 AM	Fuel fired (50 lbs.)							
11:45 AM	4.5	16	800	17.7	1.9	19.6	16.8	
11:50 AM	Fuel fired (175 lbs.), and fire checked until 1:15 PM							
1:15 PM	Fire poked and dampers opened.							
2:15 PM	11.5	.12	475	13.4	4.4	17.8	10.6	Burning down period.
2:25 PM	Fire given an excess of air to coke entire fuel bed.							
3:15 PM	Air supply changed back to normal.							
3:45 PM	9.5	.14	625	14.2	4.6	18.8	14.6	
3:55 PM	Grates shaken and fire leveled.							
4:15 PM	6.5	.15	700	15.0	3.3	18.3	15.4	
4:25 PM	Grates shaken and fire leveled.							
4:55 PM	3.0	.15	850	13.0	7.2	20.2	24.4	

The lower flue gas temperature with a deeper fuel bed may be caused by a greater absorption of heat by the water legs

at the sides of the furnace. In other words a larger proportion of heat reaches the water by radiation and conduction than by convection. Another theory is that a deep fuel bed may result

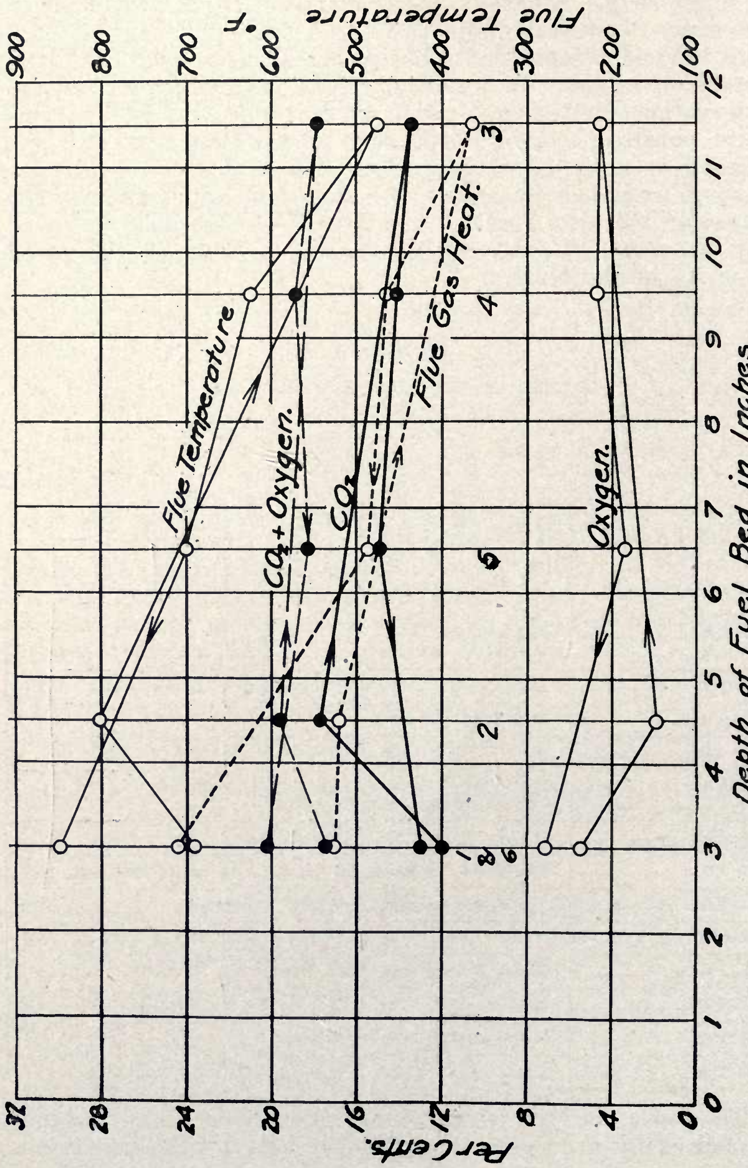

Fig.5.—Effects upon the Fire with Different Depths of Fuel Bed

in a more even distribution of air throughout the fuel bed, which would lead to a lower flue gas temperature. The nearly constant total per cents of CO_2 and oxygen tell little regarding the degree of combustion attained.

Article 23. Capacity and Efficiency. The rate of evaporation for maximum efficiency is probably different for each fuel of a different size and composition and the naming of any such rate of evaporation should be based upon a large number of tests as authority. Six full tests at different capacities varying from 24.3% to 104.2% of the rating were made with Illinois mine run coal, and four tests with capacities varying from 33.8% to 98.3% of the rating were made with Ogden lump coal to study the relation between capacity and efficiency.

The temperature of flue gases is always higher with a higher rate of combustion. With other conditions and losses the same, this would of course mean more loss of heat in the waste gases and a lower efficiency. Not so great an excess of air might be needed however which would tend to lower the amount of heat lost in the gases. Also the higher furnace temperature possible may mean better combustion of the gases. This appears to be the case with the Ogden coal where the per cent of heat unaccounted for is much less with the higher capacities, although the flue gas analysis would not indicate any definite difference. Size of fuel should also receive some consideration here. It is possible that with a higher temperature, consequent to a higher rate of burning, the volatile matter in large lumps, as in Ogden coal, is not distilled out so soon as from smaller lumps. If kept in the lumps until a greater furnace temperature is reached, better combustion of the volatile matter will be secured.

Tables X, page 44, and XI, page 46, give the most interesting results for the different rates of evaporation, and some of the same results are plotted in figure 6, page 45. The full data on these tests are given in table XIII. Boiler efficiencies are plotted in figure 6 because it is thought that they would eliminate the inequalities due to grate losses better than the boiler and grate efficiencies would.

It is surprising to note that the efficiency with Ogden coal over such a wide range of capacity developed was practically constant. As explained above the higher furnace temperature evidently produced better combustion of the gases which balanced the greater losses due to a higher temperature of the waste gases. With Illinois mine run coal such was not the case. The maximum efficiency was reached at 40% of the rated capacity. Above and below this point, a greater per cent of sensible heat was carried away by the chimney gases

TABLE X.

CAPACITY TESTS ON ILLINOIS MINE RUN COAL.

Test No.	16	13	17	14	15	18
Average fuel charge, lbs	62.5	75.0	93.3	141.7	110.0	50.0
Flue gas temperature, °F.	333	400	652	746	830	810
Flue gas, CO_2, %	6.4	10.0	10.7	10.6	13.1	12.2
Flue gas, oxygen, %	12.9	6.8	6.5	6.6	3.5	4.3
Flue gas, CO, %	0.1	0.4	0.1	0.5	0.2	0.4
Flue gas, nitrogen, %	80.6	82.8	82.7	82.3	83.2	83.1
Per cent of boiler rating developed	24.3	40.2	58.9	88.8	99.2	104.2
Boiler efficiency, %	59.1	77.4	59.4	56.0	44.7	48.4
Boiler and grate efficiency, %	46.8	64.7	52.7	52.5	42.3	43.2
Boiler Heat Balance:—						
Heating and evaporating water, %	46.8	64.7	52.7	52.5	42.3	43.2
Heating flue gases, %	10.8	8.4	15.0	18.7	17.7	17.3
Evaporating and heating moisture in fuel, %	1.1	1.2	1.3	1.4	1.4	1.4
Grate losses, %	22.3	18.0	11.7	6.9	5.6	10.5
Unaccounted for, %	19.0	7.7	19.3	20.5	33.0	27.6
Total heat in fuel as fired, %	100.0	100.0	100.0	100.0	100.0	100.0

and perhaps combustion was not so good. With a very deep bed of hot coals and with the fire checked down by dampers, a high efficiency might also be obtained at a very low rate of evaporation.

In general it would seem best to choose a boiler such that the average evaporation per square foot of heating surface would be from 2 0 to 2.5 pounds of equivalent evaporation from and at 212° F. per hour. This would correspond to 45% to 60% of the rating of the boiler tested at Ames.

In test 45 it was found necessary at times to open the fire door damper in addition to having the ash door wide open, in order to attain the high rate of evaporation with Ogden coal. The rate of evaporation in test 43 was about as low as possible with the same coal without employing other checks than the ash door damper.

The ash door was kept wide open during test 15 on Illinois mine run coal. It was necessary to use the choke damper in tests 16 and 13 with the same fuel.

Article 24. Dampers and Efficiency. Large wastes of heat

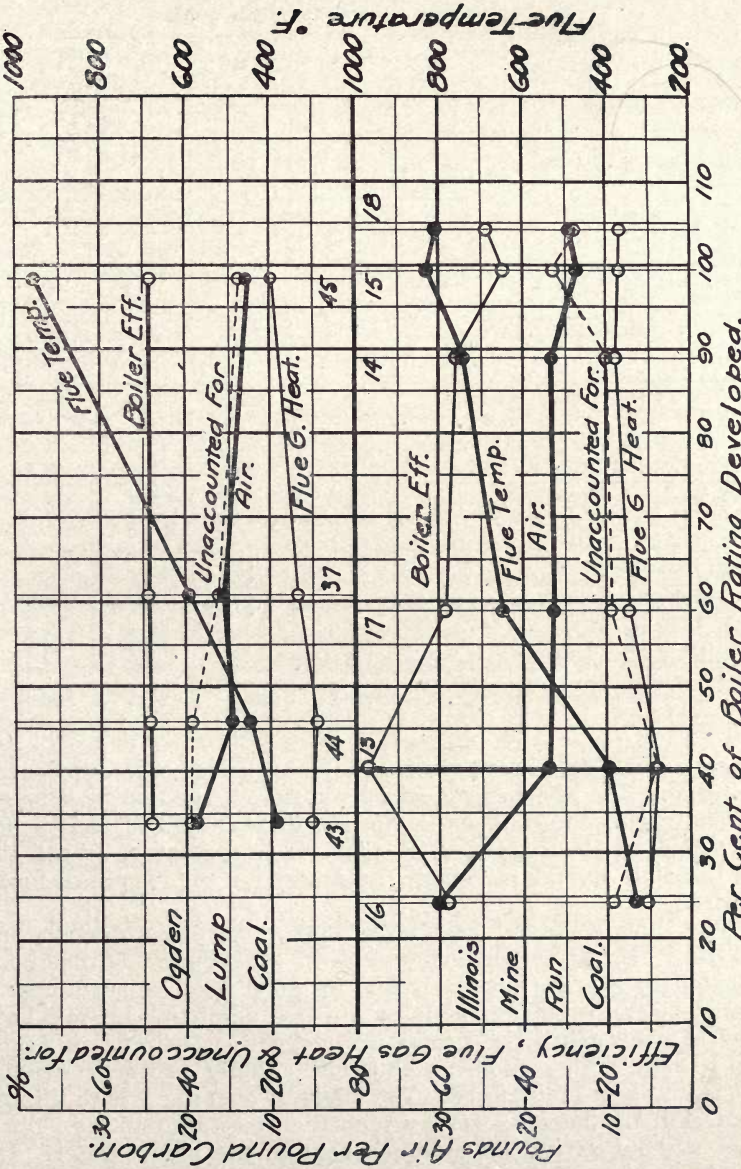

Fig. 6.—Relation between Capacity Developed and Efficiency.

often occur in practice because of the wrong use of dampers in controlling the fire or because of air leaking into the fur-

TABLE XI.

CAPACITY TESTS ON OGDEN LUMP COAL.

Test No.	43	44	37	45
Average fuel charge, lbs.	58	100	100	100
Flue gas temperature, °F.	390	450	594	965
Flue gas, CO_2, %	10.3	13.8	13.1	15.8
Flue gas, oxygen, %	8.5	4.5	5.6	2.1
Flue gas, CO, %				
Flue gas, nitrogen, %	81.2	81.7	81.3	82.1
Per cent of boiler rating developed	33.8	45.9	60.9	98.3
Boiler efficiency, %	48.6	49.0	49.3	49.1
Boiler and grate efficiency, %	48.1	47.8	46.1	47.1
Boiler Heat Balance:—				
Heating and evaporating water, %	48.1	47.8	46.1	47.1
Heating flue gases, %	10.9	9.6	13.7	20.0
Heating and evaporating moisture in fuel, %	1.1	1.1	1.3	1.3
Grate losses, %	1.1	2.5	6.4	4.0
Unaccounted for, %	38.8	39.0	32.5	27.6
Total heat in fuel as fired, %	100.0	100.0	100.0	100.0

nace. With this in view special observations were made to determine the effects produced by different damper positions.

The regulating damper in the ash door should of course be attached to the regulator, if there is a regulator, or set so as to admit enough air under the grates for the degree of heat desired.

The damper found capable of doing the most damage in wasting heat at the ordinary rates of evaporation is that one located in the fire door. It has its good uses on certain occasions, as in further checking a low fire, admitting air to a hot bed of coals when the grates are clogged or helping to keep up a very high rate of combustion. Under ordinary conditions it is best kept closed. The effect of opening it is to dilute and chill the burning gases which then pass on out the chimney without giving up as much heat to the boiler water. It might be argued that the extra oxygen thus supplied would make for better combustion, but there is usually an excess of oxygen in the furnace anyway and it seems that the cold

air coming in through the damper would be just as likely to lower the degree of combustion by its chilling effect, especially if the furnace temperature is not very high.

The normal position of the choke damper located at the point where the gases leave the boiler heating surface, is wide open. When a low fire is desired and closing the ash door damper will not cut it down enough, the choke damper should be partly closed.

The check damper which admits cold air at the base of the stack when the fire is to be checked down still more should be left closed as much as possible. When open it lowers the draft produced by the hot gases in the stack.

It is a common practice in some installations, when filling the furnace with fresh fuel and checking the fire for the night, to leave the check damper open in order to keep the fire down. It is believed that this practice should be avoided as much as possible, because of inefficiency. The furnace temperature is high enough to distill off the hydro-carbons, but is not high enough to burn them properly. Better results would be secured if the fuel bed could be built up gradually, with the check damper closed, until the whole fuel bed is coked. Then the check damper could be opened for the night or for any other period of several hours with less waste. If anthracite or coke is burned the above precautions are not so important.

Table XII shows the different effects produced by varying the damper positions. Figure 7, page50 , and figure 8, page 51, show graphically the different results. Figure 9, page 52, shows the effect of suddenly checking down a hot fire.

The same experiments as are plotted in figure 7 were repeated nearly 5 hours later with the same fire. The coal had all coked to a dry state, the fire was leveled, and the fuel bed level was 5 inches lower. Very similar results were obtained as with the comparatively green fire.

A number of lessons can be learned by a study of the diagrams illustrating the effects of operations described in table XII.

The vertical line at 10:53 A. M. on figure 7 represents the time at which the fire-door damper was opened after conditions had been constant for several minutes. Immediately all drafts dropped. There was very little difference in the total of CO_2 and oxygen, but the per cent of oxygen was greatly increased, while the flue temperature was affected but little. This shows that although no better combustion was secured, yet more waste heat was carried out by the chimney gases. When the fire door damper was closed again, conditions returned to their original trend. The shaded portion of the

TABLE XII.

EFFECTS OF DIFFERENT DAMPER POSITIONS.

Time	Boiler gauge pressure per sq. inch.	Drafts: Flue	Drafts: Furnace	Drafts: Ash Pit	Condensation	Flue Gas: Temperature	Flue Gas: CO$_2$	Flue Gas: Oxygen	Flue Gas: Sensible heat as part of fuel value
	lbs.	ins.	water		lbs.	°F	%	%	%
MAY 9, 1913.									
10:30 A. M.	Fire burning with normal position of all dampers, and fuel level 2 inches above bottom of fire door opening.								
10:30	5.7	.135	.12	.10	151	520	14.2	3.9	11.4
10:35	5.7	.14				540			
10:40	5.7	.14			183	545			
10:45	5.7	.14	.125	.115		550	14.0	4.6	12.6
10:50	5.7				214	545			
10:53	Fire door damper opened.								
10:55	5.5	.125	.085	.075		550	9.8	9.6	17.8
11:00	5.2	.12			248	560			
11:08	5.2	.12				570	9.0	10.5	19.6
11:10	Fire door damper closed.								
11:15	5.7	.14	.11	.105	292	570			
11:20	5.[illegible]		.11	.11		560	11.6	7.8	15.9
11:25	5.[illegible]	.13	.11	.11	323	540			
11:33	Choke damper nearly closed.								
11:35	5.0	.00	.015	.0[illegible]		480	12.8	6.5	12.1
11:40	4.3				362	440			
11:43	Choke damper opened about half way.								
11:50	5.4	.08	.05	.06	392	500	10.5	9.1	15.3
12:00 N.	5.6	.095	.065	.065	424	510			
12:01 P. M.	Choke damper open full way.								
12:05	5.5	.13				520			
12:10	5.5	.12	.09	.09	454	525	9.0	10.6	17.9
12:15	5.3	.13	.09		470	530			
12:16	Fuel bed level with bottom of fire door opening. Fire not touched since 10:30 A. M.								
MAY 21, 1913.									
2:10 P. M.	Fire burning with normal position of all dampers, and fuel bed level with bottom of fire door opening.								
2:10	5.9	.14	.11	.11	164	670	15.7	2.3	14.0
2:15	5.9	.14			192	680			
2:19	Ash door damper closed tight.								
2:20	5.5	.16	.14	.14	214	680	15.7	3.1	14.8
2:25	4.3	.14	.13	.13	230	650			
2:30	3.8	.14	.13	.13	247	620	14.3	5.7	15.5
2:35	3.3	.14				600			
2:36	Normal air supply again.								
2:40	5.8	.13	.07	.03		770	15.7	4.3	18.2
2:42	6.5					800			
2:50	5.0	.12	.08	.07		710			

2:53 ----------	Fuel bed leveled—4 inches below bottom of fire door opening.								
2:55 ----------	5.2	.13	.10	.06	--------	700	15.9	1	13.9
2:57 ----------	Choke damper nearly closed.								
3:00 ----------	4.8	.01	.005	.00	--------	680	--------	--------	--------
3:05 ----------	2.5	.005	.005	.00	--------	580	15.4	3.6	12.7
3:10 ----------	2.0	.000	--------	--------	--------	480	--------	--------	--------
3:13 ----------	Normal position of all dampers again.								
3:15 ----------	3.0	.12	.08	.04	--------	650	16.9	3.8	14.7
3:20 ----------	6.0	.13	.11	.08	--------	740	--------	--------	--------

diagram represents the approximate amount of sensible heat lost by opening the damper.

Partly closing the choke damper, illustrated on figure 8, does not show any such definite change in the chimney gas losses. Its main effect is to greatly lower the drafts and check down the fire.

Checking down the fire by closing the ash door damper at 2:19 P. M. is illustrated on figure 9. The fire is checked and the flue temperature lowered much in the same way as when the choke damper is partly closed. The vertical line at 2:53 P. M. represents the time when the fire was stirred and leveled. As always occurs in every day practice when the fire is so disturbed, more smoke is produced, and the sum of CO_2 and oxygen is lowered. While the excess of air is lowered and consequently, less *sensible* heat is carried out by the chimney gases, yet a greater per cent of combustible gases are discharged, unburnt, as indicated by the smoke and low total per cent of CO_2 and oxygen. This illustrates one of the possible ways of wasting heat when the fire is poked and disturbed unnecessarily.

The idea is sometimes stated that although the draft available is ample to produce the rate of combustion desired, yet considerable more efficiency would be secured were the draft stronger or more intense. It may be that this idea is emphasized too much *since a sharper draft could not be allowed full action upon the fire, anyhow, because if it were, the rate of combustion would become too high.* Just so much air must be passed through a given fire in a given condition and position to produce the rate of combustion desired. This is true, however, *that a low stack, an obstruction in the stack, or admittance of cold air to the stack, will require more heat in the gases leaving the furnace to produce the draft needed to draw the required air through the fire.* Experiments would be interesting, if made, to determine just how much more chimney heat would be needed to overcome the friction due to an obstruction in the pipe and to overcome the effect of a low stack and the effect of admitting cold air to the stack.

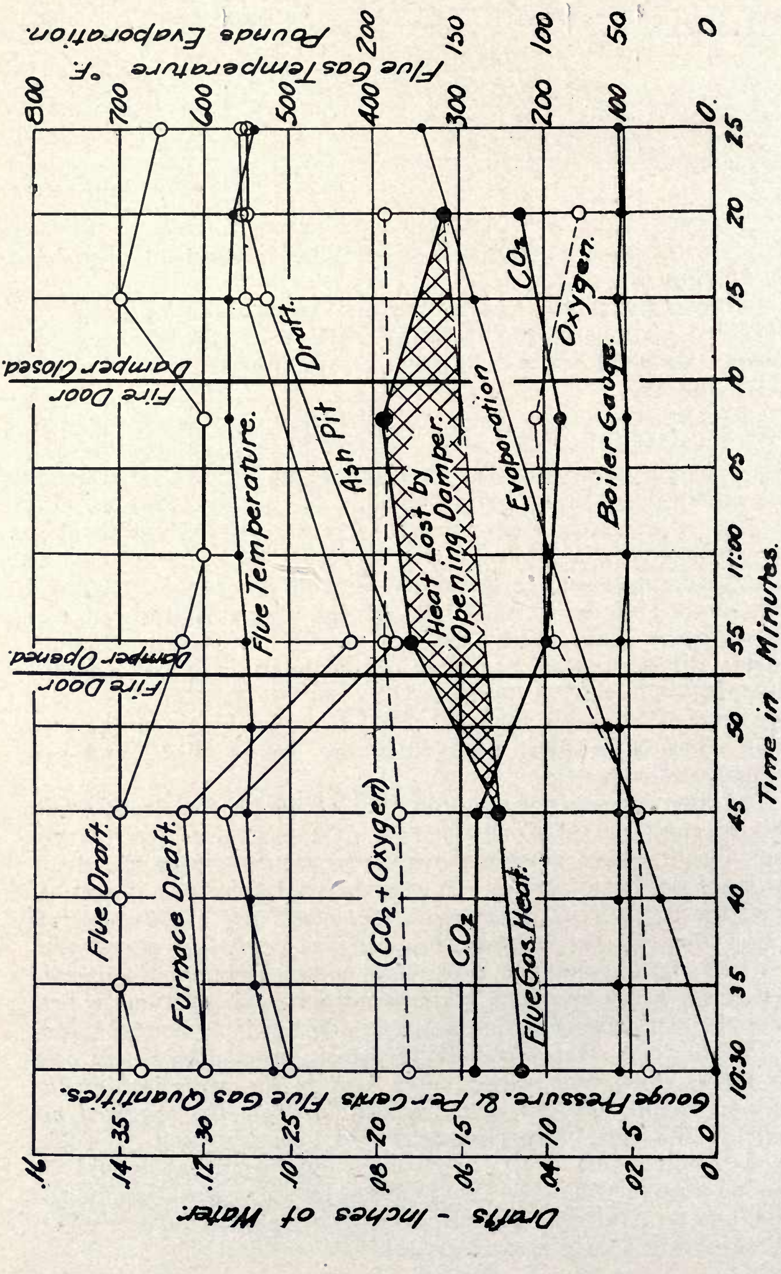

Fig. 7—Effects of Admitting Cold Air to the Fire above the Grate.

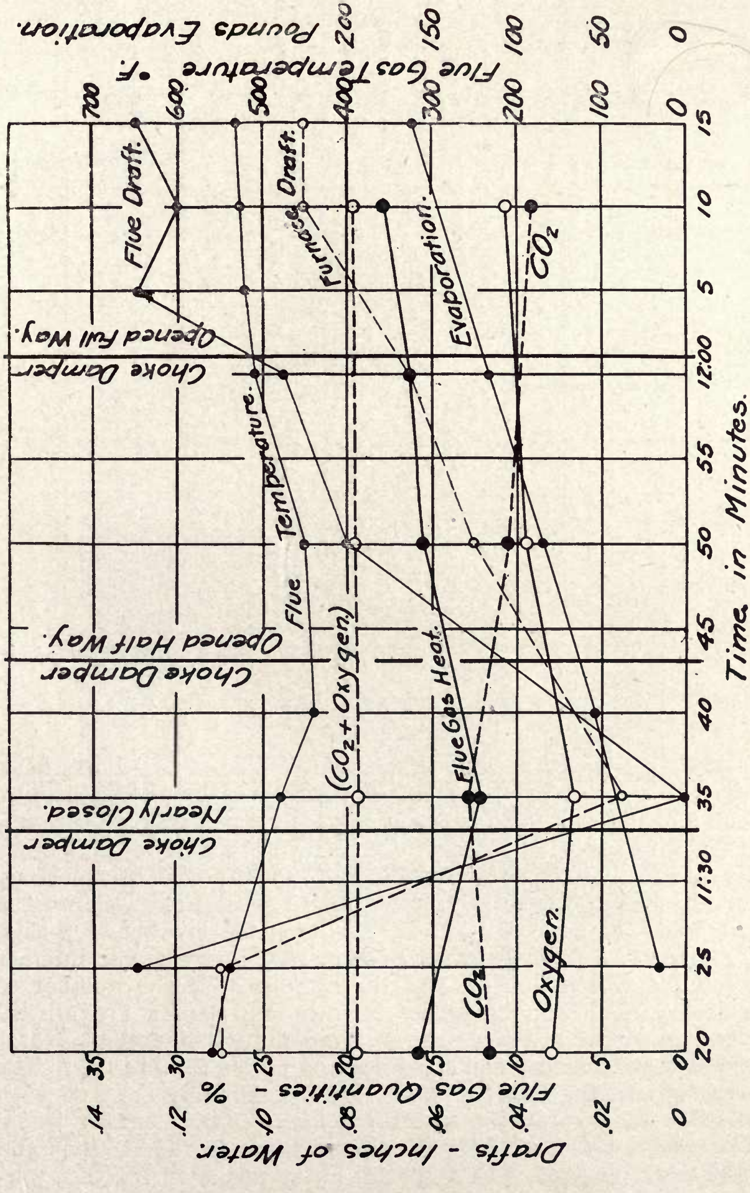

Fig. 8—Effects of Partly Closing Choke Damper.

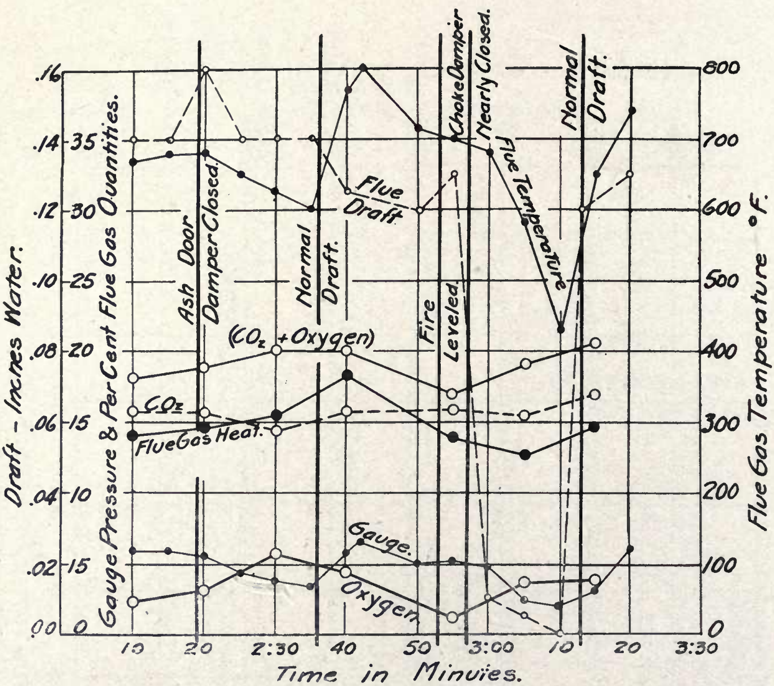

Fig. 9—Effects of Checking Down Hot Fire.

VIII. EQUIPMENT.

Article 25. Boiler and Dimensions. The steam house heating boiler used in the tests at Ames was of the horizontal sectional type. It was located in the basement of the Mechanical Engineering Laboratory of the Iowa State College. Figure **10,** page 53, is a photographic view of the boiler as set up for the tests. Figure 11, page 54, is a sectional view of a 15" boiler of the same type. The maker's number is S-25-6, the letter S referring to the sectional steam type, the number 25 to the size in inches, and the number 6 to the number of sections. The ash chamber, furnace and boiler are all enclosed in 6 vertical cast iron sections bolted together. Water heating surfaces are at both sides and above the fire box. The sections and the back of boiler were completely covered with an 85% magnesia heat insulation about 1 or 1.5 inch thick. The cracks between the sections and between the sections and base were plugged with a special putty provided for that purpose in order to make the joints air tight. The covering and calking were in fairly good condition during the time of the

Station tests. Five sections of rocker grates run cross-wise of the furnace and are operated by two levers at the front of the boiler.

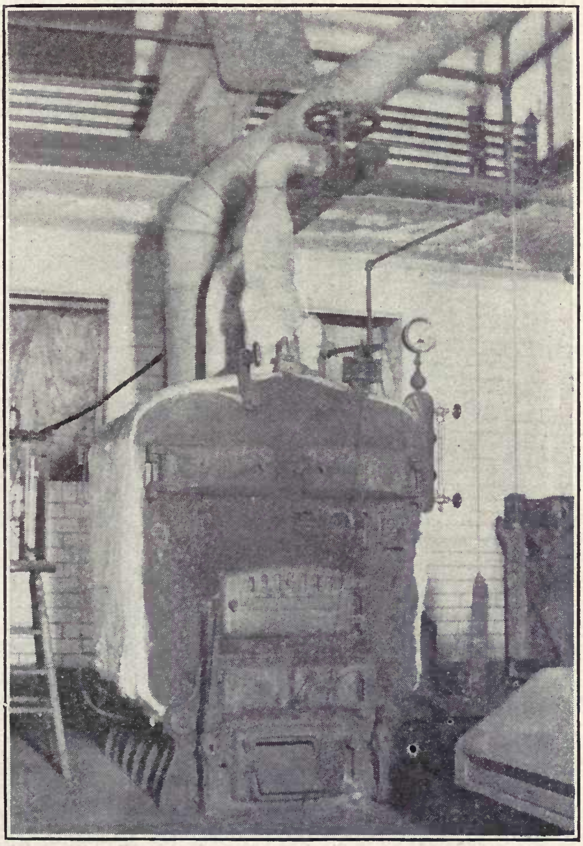

Fig. 10—Photographic Veiw of Boiler Set up for Operation at Ames.

The fittings consisted of a glass water level gauge, a steam pressure gauge, a pop safety valve and a damper regulator. The regulator consists of a brass corrugated expansion cylinder mounted on top of the boiler and connected directly to the steam pressure. The cylinder supports a counter balanced pivoted lever which in turn is connected to the regulating damper by a chain.

The smoke pipe leading from the boiler is 11 inches in diameter and is inclined as shown in the photograph, to connect

with the chimney. The top of chimney is about 43 feet above the top of boiler and about 11 feet away in a horizontal direction

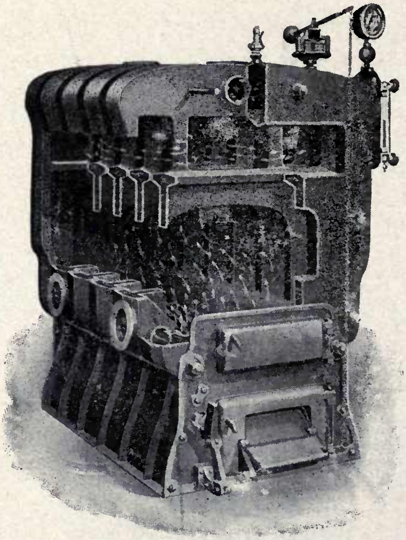

Fig. 11.—Sectional View of 15 inch Boiler of Same Type and Same Number of Sections as the One Tested at Ames.

Steam is taken from the boiler through two vertical risers which connect above the boiler and lead into a steam pipe which carries the steam to a surface condenser. In the steam pipe just above the boiler is located the regulating throttle valve. A pulley with index is attached to the valve handle, and around this pulley runs a cord which has its ends threaded through supporting pulleys and attached to weights. This arrangement was for ease in controlling rate of evaporation.

The boiler dimensions and specifications are as follows:

Rated Capacity in Radiating Surface..	1,350	sq. ft.
Number of Sections..................	6	
Rated Gauge Pressure...............	2	lb. per sq. in.
Total Length	66.875	in.
Width Inclusive of Trimmings........	47.25	in.
Height Inclusive of Trimmings.......	64.125	in.
Width of Base on Floor..............	34.75	in.
Length of Base on Floor.............	49	in.
Width Inside Ash Pit...............	28	in.
Length Inside Ash Pit...............	42.875	in.
Grate Area	6.80	sq. ft.
Average Fire Pot Area..............	8.10	sq. ft.

Size of Fire Door Opening...........	8.5x18	in.
Fuel Depth from Grate to Center of Fire Door	14.25	in.
Direct Water Heating Surface........	49.45	sq. ft.
Flue Water Heating Surface.........	29.12	sq. ft.
Superheating Surface	0.00	sq. ft.
Total Heating Surface...............	78.57	sq. ft.
Ratio of Direct to Total Heating Surface	.63	
Ratio of Total Heating Surface to Grate Area	11.5	
Number of Steam Outlets............	2	
Diameter of Steam Outlets...........	4	in.
Height of Water Line...............	49	in.
Size of Smoke Pipe..................	11	in.
Kind of Draft......................	Natural	
Kind of Fuel Recommended..........	Stove Size Anthracite	
List Price Complete................	$505.00	

Article 26. Apparatus Employed. Fahrenheit laboratory thermometers were used for taking all temperatures except that of the flue gas. A dial reading expansion pyrometer (Tagliabue make) was used for the flue gas with the stem extending into the stack about a foot above the boiler, so as to be in the direct path of the gases as they left the boiler heating surfaces. The temperature of entering feed water was obtained through an oil filled thermometer well placed in the supply pipe.

Throttling calorimeters had been connected to each of the magnesia covered steam risers, but the steam was found to be of such an even quality that only the calorimeter on the front riser was used. It was of the Carpenter type.

The common portable type of Orsat apparatus was employed for analyzing flue gas. It can be seen standing on a stool at the reader's left in figure 10.

Ellison inclined differential draft gauges were employed for reading the drafts in flue, furnace and ash pit.

A mercury barometer in another laboratory room gave atmospheric pressures direct.

Ordinary platform scales were used for weighing the fuel, ash and refuse, and condensation. The fuel and ash were weighed in bunkers and the condensation in a galvanized iron tank.

Figure 12 is a diagram showing the arrangement of boiler with connected apparatus.

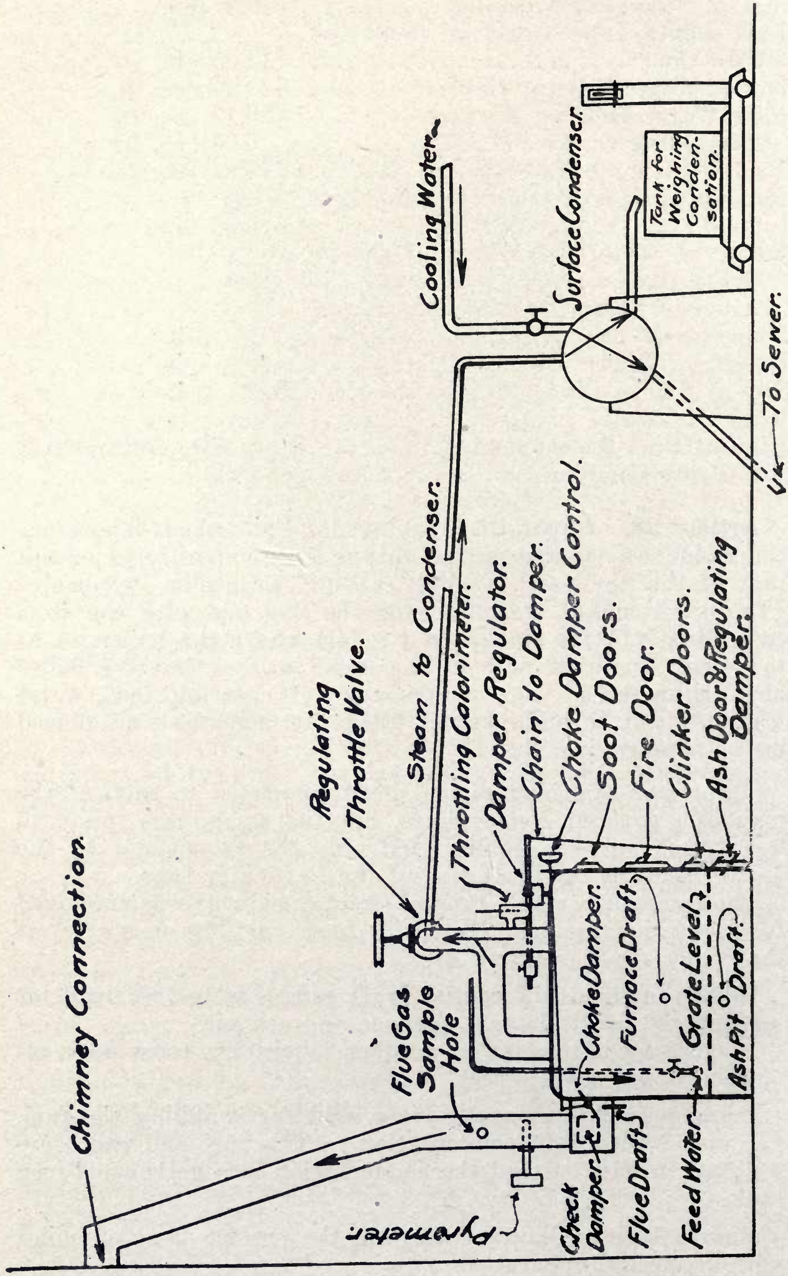

Fig. 12.—Diagram of Boiler and Connections for the Ames Tests

IX. METHOD OF CONDUCTING TESTS.

Article 27. Fuel, Fire and Ash. Each sack of fuel was sampled upon being emptied into the weighing bunker. The total sample thus collected for a single test or for more tests upon the same kind and grade of fuel was broken up and quartered until an amount small enough to be contained in a one quart fruit jar was obtained. The cover was then screwed down tightly with a rubber seal on the jar and the sample was put away until analyzed.

For proximate and calorific analyses, the sample was crushed and quartered until the amount in hand was a representative portion of several grams. It was then ground and all passed through a 100 mesh sieve. The common process of proximate and calorific analysis was then employed. The Parr bomb calorimeter was used for the calorific determination. Samples were always run in duplicate, and if they failed to check within 1% of each other, other trials were made until a proper check was secured. In recording the per cents of fuel constituents, no refinements smaller than .1 of 1% were made. One can readily realize that it is unnecessary to attempt to determine results to .01 of 1% when errors in sampling the fuel may be as much as 1% or 2%, and when duplicate weights in the analysis do not check each other closer than .2 or .3 of 1%.

Proximate analyses were made upon the ash and refuse from tests 1 to 12, inclusive, but the results were inconsistent to a certain extent. Were the results of these analyses believed the ash and refuse would, in some cases, have contained more pounds of actual ash than existed in the original fuel; and in some cases much less, when compared with the analyses of the original fuels. To obtain a fair sample of ash and refuse for analysis, it would seem necessary to crush the entire amount of ash and refuse and quarter it down to the required amount for grinding before analyzing. Per cent of ash in ash and refuse for tests 13 to 49 was determined from the fuel analyses as explained in article 32 under Formulas and Methods.

The fire for each test was started with kindling wood and a weighed amount of coal or coke. It was allowed to burn until steam was being generated and condensation was running from the condensor to the weighing tank, and the fire had reduced itself to a bed of coals 3 or 4 inches thick with practically all volatile matter gone, and general conditions had become constant. This usually required from one to two hours. At this point the time, condition of fire and water level were noted, and the first charge of fuel for the test proper

was fired. End of the test was called when the observer judged the fire to have the same heat value left upon the grate as at the beginning of the test proper. The ash pit was cleaned at the beginning of the test proper. After the end of test the fire was left until completely dead, when the grates were dumped. If any pieces of coke above 1 or 2 inches in size were left, they were picked out and the remaining ash and refuse was weighed. From this weight was deducted the proportional weight due to the kindling coal or coke, and the remainder was recorded as the total ash and refuse for the test proper.

For the short firing tests, a fresh fuel charge, often of about 100 pounds, was fired just after the fuel bed had dropped to a level of about 5 or 6 inches, but before the steam pressure had fallen off. For long firing tests, the entire amount of fuel tested was fired at the beginning of the test proper. Sometimes this was fired in two or three sections at intervals of a few minutes, to avoid killing the fire. Also some of the live coals were raked to the front of the furnace and more of the fresh fuel was thrown to the back of the furnace to avoid too great a loss in furnace temperature. This would also give the volatile gases a better chance to burn since in this boiler they must come to the front of the furnace before passing out. The fire was poked and leveled during the trial as required by clinkering, holes and dead spots.

Nearly the same style of firing was employed with all classes of fuel. Anthracite and coke, however, were spread more evenly over the entire grate area.

In the general tests the choke damper was wide open and the check damper was closed to give the fire the greatest freedom. Air supply to the furnace was regulated by the ash door damper connected to the automatic regulator. Tests 1 to 12 were made with the fire door damper open. All of the other general tests were made with it closed.

Soot was cleaned from the boiler flues at the beginning of each test.

Article 28. Evaporation. The rates of evaporation at 5 pounds boiler pressure had been previously determined for different throttle openings as indicated by the index on the valve hand wheel. The approximate rate of evaporation then desired for each test was gained by proper adjustment of the valve.

The system of lever, weight and chain of the damper regulator was adjusted so as to keep a boiler pressure of about 5 pounds. The regulating damper was usually held by the automatic regulator at an opening less than one inch wide, the

exact opening depending of course upon the fuel, rate of evaporation and other factors. When the boiler pressure became too high, the damper would be automatically closed a little more, and when the pressure was too low the damper would be automatically opened a little wider.

The test proper was not begun until a steady stream of cooling water was running through the condensor and a stream of condensation was flowing from the condensor to the weighing tank. It was not found necessary to operate the condensor pump, the steam pressure from the boiler being enough to force out the condensation. The condensation from the boiler was weighed instead of the water fed to the boiler. This eliminates to a greater extent any error due to inequalities of boiler water levels at the beginning and end of tests. The tank used for weighing the condensation holds about 1,000 pounds when full and so needed to be emptied once during an ordinary test. The steam escaping through the throttling calorimeter was collected and weighed once during the tests, and a correction of 2 pounds per hour was accordingly made for all tests.

Article 29. Flue Gas and Drafts. For tests 1 to 31 inclusive, continuous flue gas samples were taken. An air tight can holding about 5 or 6 gallons and having a pet cock at the top and one at the bottom was filled with water which had been previously saturated with the gas. The top pet cock of this can was connected by a rubber tube to a ⅛″ iron tube extending into the stack for drawing out the gas. This iron tube was perforated inside the stack. The lower pet cock was connected by a rubber tube to the lower pet cock of another exactly similar can, sitting at a lower level than the first. When it was desired to begin taking a sample all the pet cocks were opened just enough to produce the rate of flow desired. A continuous sample could thus be secured extending over a period of several hours. The time chosen was such as to represent as nearly as possible the average of the whole test. The gas thus collected was afterward tested for CO_2 and oxygen in the Orsat apparatus. CO was tested for in the gases from tests 13 to 18 and 24 to 26 inclusive.

After test 31, the continuous method of sampling was abandoned because of the difficulty of properly saturating the water and because some variable results had been obtained from different analyses of the same sample. After test 31 then, the gas sample was drawn directly from the stack into the Orsat apparatus.

Sometimes one and sometimes two differential draft gauges were used for measuring the drafts in three different points.

The gauge was connected by rubber tubing to a $1/8''$ iron tube which extended into its respective chamber, the draft of which was to be measured. One extended into the side of the ash pit, one into the side of the furnace, and one into the smoke pipe just under the choke damper.

Article 30. Readings. The following readings were taken at 20 minute intervals during the tests:

boiler pressure,
draft in flue,
draft in furnace,
draft in ash pit,
temperature of boiler room,
temperature of steam in calorimeter,
temperature of gases from boiler, and
weight of condensation.

The following readings were taken at irregular intervals, the time depending upon necessity of catching any important variations that might occur:

barometric pressure,
temperature of external air,
temperature of water to boiler, and
flue gas analysis.

Fuel was weighed just before firing.

When the continuous gas sampler was used, gas was collected from a certain time after one firing to the same time after the next firing in the short firing tests. For long firing tests, gas was collected for 3 or 4 hours during the middle part of the run or for shorter times near the beginning and end of the test.

When the gas was analyzed directly from the stack, samples were taken at intervals of about one hour for the long firing tests and at shorter intervals between the times of two firings for the short firing tests.

In general the trials were run and readings were taken in accord with the A. S. M. E. code for boiler trials. The readings were recorded upon boiler test log blanks printed for that purpose.

Observations from which table IV, Fuel Characteristics, was compiled, were made at appropriate times and recorded upon the back of log sheets. No definite measurements were made especially for these characteristics.

X. CALCULATION OF RESULTS.

Article 31. Factors and Constants. Factors and constants quoted or used by different authorities vary somewhat and it

was thought best to record here those actually employed herein.

The heat value of 1 pound of pure carbon is quoted at from 14,500 to 14,600. The value used in these calculations is 14,500 British thermal units per pound pure carbon.

Marks and Davis steam tables were used for heat values of water and steam. The latent heat of evaporation at 212° F. is given in these tables as 970.4 B. T. U. which is somewhat higher than the older value of 965.4.

It is considered that one square foot of cast iron radiating surface requires heat each hour equivalent to that required to evaporate .25 pound of water from and at 212° F. A constant sometimes used is .30 pound, but .25 was chosen for these calculations because it is the factor used by the makers of the boiler who give it its rating.

One boiler horse power is defined as the equivalent evaporation of 34.5 pounds of water from and at 212° F. per hour.

Other quantities are given without discussion.

Ratio of nitrogen to oxygen by volume in the air, 3.8.

Weight of air required for perfect combustion of one pound of carbon, 11.7 pounds.

Specific heat of flue gases at stack pressure, .24.

Specific heat of superheated steam at stack pressure, .48.

Ratio of inches of mercury in barometer to atmospheric pressure in pounds per square inch, 29.921: 14.696.

Article 32. Formulas and Methods. Oven dried samples of fuel were always used for calorific analysis. The B. T. U. per pound of fuel as fired and per pound combustible were then calculated with the aid of the proximate analysis.

The weight of actual ash in ash and refuse was assumed to be the same as contained in the original fuel as determined by the proximate analysis. Some ash was perhaps lost in the gases passing out the chimney, but with the low draft employed it was assumed to be negligible. The balance of ash and refuse was assumed to be combustible made up of fixed carbon.

The figure just before each of the following paragraphs refers to an item number in table XIII to which item the formula applies. The last five paragraphs—Nos. 77 to 81—come under the boiler heat balance, and each represents a per cent of the total heat value of the fuel as fired.

37. The B. T. U. in ash and refuse per pound dry fuel =
$\frac{\text{(Lbs. ash and refuse, total)}}{\text{(Lbs. dry fuel, total)}} \times$ (% combustible in ash and refuse) $\times 14500$.

The averages of temperatures, pressures and flue gas analyses were used for the final calculations.

21. Ratio of air supplied to air used, $r = \dfrac{N}{N-(3.8\times O)}$

where N is the per cent of nitrogen and O is the per cent of oxygen by volume in the flue gas. N was taken as the difference between 100% and the total per cent of CO_2 and oxygen. When CO was determined, it was also included in the formula.

22. Air supplied per pound carbon, $A=11.7\times r$, in pounds. Pounds flue gas per pound carbon$=A+1$.

31. Total dry fuel=pounds fuel as fired×(100%−% of moisture).

32. Combustible consumed=combustible fired—combustible in ash and refuse.

Hourly quantities were obtained from the division of total quantities by the length of test in hours.

44. Quality of steam, $x = \dfrac{H-Q+.48(T'-T)}{L}$

in which H=total heat above 32° F. of the steam at calorimetric pressure,

Q=total heat of the liquid above 32° F. at boiler pressure,

T′=temperature (°F.) in calorimeter,

T=normal temperature (°F.) of steam at calorimetric pressure and

L=latent heat of evaporation at boiler pressure.

45. Factor of evaporation, $Fe = \dfrac{H-(t-32)}{L}$, in which

H=total heat in the steam at boiler pressure,

t=temperature of feed water in °F., and

L=970.4, latent heat of evaporation at 212 °F.

67. Boiler efficiency$= \dfrac{970.4\times \text{equiv. evap. } (212^\circ \text{ F.})}{\text{B. T. U. in combustible consumed}}$

68. Boiler and grade efficiency$= \dfrac{970.4\times \text{equiv. evap. } (212^\circ \text{ F.})}{\text{B. T. U. in total fuel as fired}}$

77. Heating and evaporating water=boiler and grate efficiency.

78. Heating flue gases=pounds flue gas per pound carbon× .24 $(T'-t)\div 14{,}500\times(100\%-\%$ loss through grate), in which

T′=temperature (°F.) of gases leaving boiler, and

t=room temperature (°F).

79. Evaporating and heating moisture in fuel=(% moisture in fuel as fired)×(M)÷(B. T. U. per pound fuel), in which

$M = (T - t) + 970.4 + .48\ (T' - T)$, in which
$T = 212$, t = room temperature (°F.), and T' = temperature (°F.) of gases leaving boiler.

80. Losses through grate = (B. T. U. in ash and refuse per pound dry fuel) ÷ (B. T. U. per pound dry fuel).

81. Unaccounted for = 100% — total of per cents accounted for.

Article 33. Complete Illustrative Computation for a Particular Test. For better illustrating the details of calculations employed, the results of test No. 41 are worked out in this article. The item numbers refer to those used in table XIII.

Observations.

Item No.		
1.	Test number	41
2.	Kind of fuel	Centerville lump
3.	Kind of firing	S (= short)
4.	Date of trial	2-26-13
5.	Duration of trial, hours	7.67
6.	Average atmospheric pressure, ins. mercury	28.90
7.	Average boiler gauge pressure	4.9
9.	Average draft in flue, ins. water	.14
10.	Average draft in furnace, ins. water	.13
11.	Average draft in ash pit, ins. water	.12
12.	Average temperature (°F.), external air	24
13.	Average temperature, boiler room air (°F.)	67
14.	Average temperature, feed water (°F.)	59
15.	Average temperature, steam in calorimeter (°F.)	213
16.	Average temperature, flue gases (°F.)	603
	Average of Flue Gas Analysis—	
17.	CO_2, %	13.0
18.	Oxygen, %	6.0
19.	CO, %	——
20.	Nitrogen, % (by difference)	81.0
	Fuel Analysis, Proximate—	
23.	Moisture, %	9.2
24.	Volatile matter, %	37.5
25.	Fixed carbon, %	46.5
26.	Ash, %	6.8
28.	Calorific analysis, of fuel, B. T. U. per pound dry fuel	13,700

30. Fuel as fired, total pounds......... 300
33. Ash and refuse, total pounds....... 40
46. Total water evaporated, pounds.... 1,392
56. Number of firings during test..... 3
69. Cost of fuel in dollars per 2,000 pounds 4.00

Calculations.

Item No.

8. Boiler pressure, absolute $=4.9+(28.90\times\frac{14.696}{29.921})=$ 19.1 lb. per sq. in.

21. Ratio—air supplied to air used, $r=\frac{81.0}{81.0-(3.8\times6.0)}$ $=1.39$.

22. Air supplied per pound carbon=11.7lb×1.39=16.3lb.
Pounds flue gas per pound carbon=1lb+16.3lb=17.3lb.

27. B. T. U. per pound fuel as fired=(100.0%—9.2% moisture)×13,700=12,450 B. T. U.

29. B. T. U. per pound combustible=12,450÷(37.5% volatile matter+46.5% fixed carbon)=14,800 B. T. U.

31. Total dry fuel=300lb×(100%—9.2% moisture)=272 pounds.

32. Total combustible consumed=272lb—40lb ash and refuse = 232 pounds.

34. Ash and refuse, per cent of fuel as fired=40lb÷300lb= 13.3.

36. Ash and refuse, per cent ash=(300lb×6.8%)÷40lb= 51.0.

35. Ash and refuse, per cent carbon=100.0%—51.0%=49.0

37. Ash and refuse, B. T. U. per pound dry fuel=40lb÷272lb×49%×14,500 B. T. U. = 1040 B. T. U.

38. Per hour, fuel as fired=300÷7.67=39.1lb.

39. Per hour, dry fuel=272÷7.67=35.5lb.

40. Per hour, combustible consumed=232÷7.67=30.3lb.

41. Per hour, fuel as fired per sq. ft. of grate surface =39.1lb÷6.80 sq. ft.=5.75lb.

42. Per hour, B. T. U. supplied in dry fuel=35.5lb×13,500 =486,000 B. T. U.

43. Per hour, B. T. U. supplied in combustible consumed =30.3lb×14,800=448,000 B. T. U.

44. Quality of steam $=\frac{1149.7-193.7+.48(213-210.2)}{961.4}=99.5\%$.

45. Factor of evaporation $=\frac{1155.3-(59-32)}{970.4}=1.162$.

47. Total dry steam evaporated=1392×99.5%=1385℔.

48. Equivalent evaporation (212°F.)=1385℔×1.162=1610℔.

49. Per hour, actual evaporation=1392℔÷7.67=182℔.

50. Per hour, dry steam=1385℔÷7.67=181℔.

51. Per hour, equiv. evap. (212°F.)=1610℔÷7.67=210℔.

52. Per hour, equiv. evap. (212°F.) per sq. ft. boiler heating surface=210℔÷78.57 sq. ft.=2.63℔.

53. Per hour, B. T. U. absorbed by steam=210℔×970.4=203,500.

54. Per hour, B. T. U. absorbed per ℔ dry fuel=203,500÷35.5℔=5,730.

55. Per hour, B. T. U. absorbed per lb. combustible consumed=203,500÷30.3℔=6,710.

57. Average time between firings=7.67÷3=2.56 hours.

58. Average weight of charge=300℔÷3=100 pounds.

59. Boiler horse power developed=210℔÷34.5℔=6.09.

60. Square feet of radiating surface served by equivalent of evaporation=210÷.25=840.

61. Per cent of builder's rating developed=840÷1350=62.2.

Evaporative Performance—

62. Actual water per pound fuel as fired=1392÷300=4.64 lb.

63. Equiv. evap. (212°F.) per pound fuel as fired=1610÷300=5.37℔.

64. Fuel as fired per hour per 100 sq. ft. radiating surface developed$=39.1\div\frac{840}{100}=4.65$ lb.

65. Actual water per pound combustible=4.64÷(37.5+46.5)%=5.52℔.

66. Equiv. evap. (212°F.) per pound combustible=5.37÷(37.5+46.5)%=6.38℔.

67. Boiler efficiency=
203,500 B. T. U. ÷ 448,000 B. T. U. = 45.4%,
or 6,710 B. T. U. ÷ 14,800 B. T. U. = 45.4%.

68. Boiler and grate efficiency=
203,500 B. T. U. ÷ 487,000 B. T. U. = 41.8%,
or 5,730 B. T. U. ÷ 13,700 B. T. U. = 41.8%.

70. Cost per million B. T. U. in fuel=
$4.00÷(12,450 B. T. U. × 2000℔)×1,000,000=16.1c.

71. Cost of evaporating 1000 pounds water under actual conditions at actual fuel price=$4.00÷2000℔÷4.64℔×1000lb. =43.1c.

72. Cost of equivalent evaporation (212°F.) of 1000℔ water at actual fuel price=$4.00÷2000℔÷5.37℔×1000lb.=372c.

73. Cost of serving 100 sq. ft. of radiation per hour at actual fuel price=$4.00÷2000lb×4.65lb=.93c.

74. Cost of evaporating 1000 pounds water under actual conditions at fuel price of $1 per ton=43.1c×($1÷$4)=10.8c.

75. Cost of equivalent evaporation (212°F.) of 1000lb water at fuel price of $1 per ton=37.2c×($1÷$4)=9.3c.

76. Cost of serving 100 sq. ft. of radiation per hour at fuel price of $1 per ton=0.93c×($1÷$4)=0.23c.

Boiler Heat Balance—

77. Heating and evaporating water = boiler and grate efficiency=41.8%.

80. Grate losses=1040 B. T. U. ÷ 13,700 B. T. U. = 7.6%.

78. Heating flue gases=
.24(603—67)÷14,500×(100.0%—7.6%)=14.1%.

79. Heating and Evaporating Moisture in Fuel = 9.2%×[(212—67)+970.4+48(603—212)]÷12,450 B. T. U. = 1.0%.

81. Unaccounted for=
100.0%—(41.8+14.1+7.6+1.0)%=35.5%.

82. Total heat in fuel as fired=
(35.5+41.8+14.1+7.6+1.0)%=100.0%.

XI. LOGS OF TYPICAL TRIALS.

Article 34. Analysis of Readings. Figures 13, 14, 15 and 16, pages 68 to 71, are graphical logs of some of the most important readings from four different trials. They illustrate the time and time intervals at which different readings were made, and bring to light in a rough way some of the relations between cause and effect. The time at which the fuel charge is located represents the end of the period for which that charge was supposed to serve. In figure 15 the location of each of the first two points represents the time at which the next charge was fired.

In figure 13 the arrow pointed lines show the time over which flue gas was collected, when a continuous sample was taken, and the analysis of the same sample. It will be noted that comparatively little variation was recorded during this trial in any of the quantities. This comparative constancy was due partly to the nature of the fuel, Solvay coke, which required little attention during the trial. The boiler pressure and rate of evaporation however had begun to drop slightly before the end of test.

Figure 14 shows considerable variation in the readings, indicating that the fire required more poking and was otherwise uneven.

Figure 15 illustrates a test of short firing, each firing of a fuel charge causing a disturbance of other conditions. Most

of the flue gas analyses were made between the last two firings of fuel.

Figure 16 when compared with figure 15 illustrates the smaller fluctuations, usually resulting in better economy obtained with long firing of the same fuel.

Flue temperatures are higher at the beginning than for the average in all four of these cases. This is due to the charge of fuel fired at the start of test proper. A greater flue temperature is required to produce a sufficient draft to get the fresh charge ignited and at the same time give up the required heat to the water.

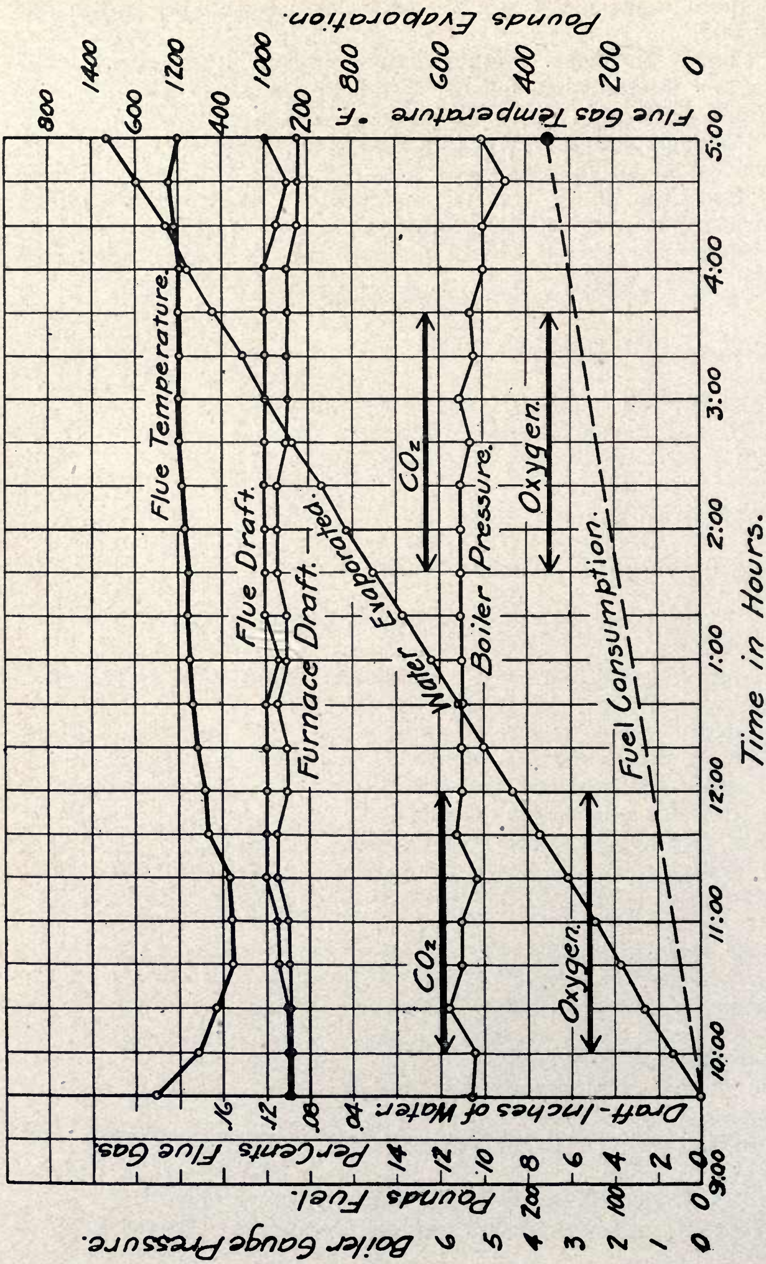

Fig. 13—Log of Test No. 23—Long Firing with Solvay Coke.

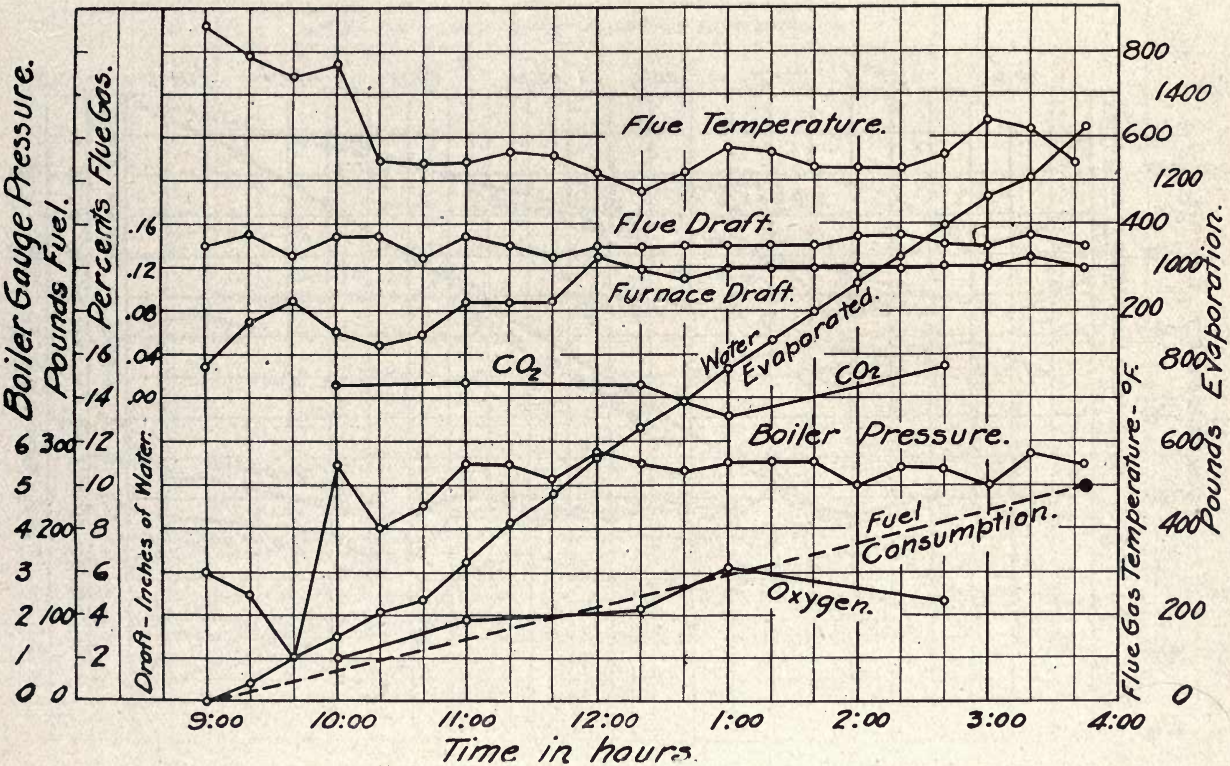

Fig. 14—Log of Test No. 34—Long Firing with Empire Lump Coal

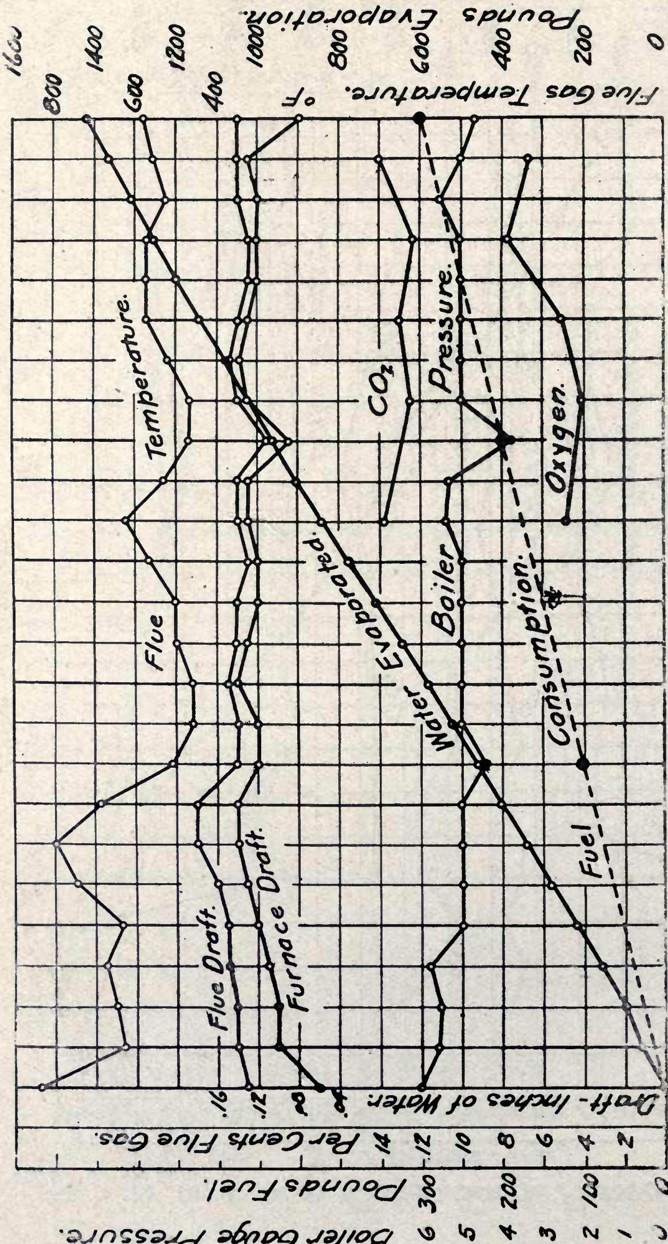

Fig. 15—Log of Test No. 37—Short Firing with Ogden Lump Coal.

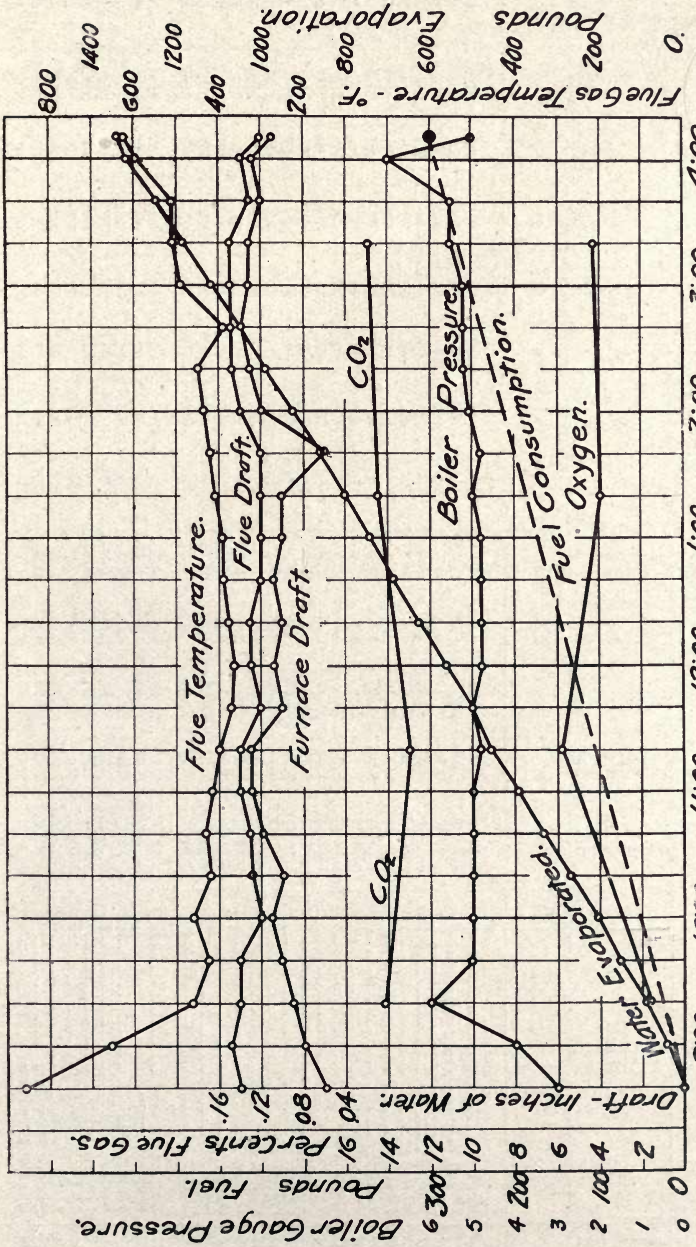

Fig. 16.—Log of Test No. 38—Long Firing with Ogden Lump Coal.

TABLE XIII.

DETAIL DATA ON INDIVIDUAL TESTS.

					Average Pressures			Average Drafts (ins. of water)			Average Temperatures (°F)				
Test Number	Kind of Fuel	Kind of Firing	Date of Test	Duration of Trial, Hours	Barometer, Ins. Mercury	Boiler Gauge, lbs per sq. in.	Boiler Absolute, lbs. per sq. in.	Flue	Furnace	Ash Pit	External Air	Boiler Room Air	Feed Water	Steam in Calorimeter	Gases from Boiler
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
3	Boone	S	3-16-12	8.0	29.09	4.94	19.24	.126	.068	.069	36	66	47	214.6	630
4	Boone	S	3-20-12	8.08	29.12	5.38	19.68	.122	.087	.086	73	66	58	216.0	653
24	Boone	S	7-22-12	6.33	29.17	5.4	19.7	.099	.082	.063	75	80	66	214	497
27	Boone	S	10-24-12	7.25	29.16	5.0	19.3	.115	.10	.08	54	64	58	214	590
28	Boone	L	10-25-12	7.25	29.23	5.0	19.3	.125	.09	.08	57	65	60	214	520
46	Buxton	L	4-15-13	8.5	29.10	5.0	19.2	.11	.07	.06	70	74	56	214	600
47	Buxton	L	4-16-13	8.25	28.97	4.8	19.0	.11	.08	.07	70	75	60	213	575
41	Centerville	S	2-26-13	7.67	28.9	4.9	19.0	.14	.13	.12	24	67	59	213	603
42	Centerville	L	2-27-13	8.25	29.0	5.0	19.2	.12	.10	.09	20	62	57	214	560
32	Colfax	S	11-29-12	7.25	29.24	5.0	19.3	.13	.10	.09	44	66	58	214	630
33	Colfax	L	12- 3-12	7.75	28.85	4.7	18.8	.12	.09	.07	40	60	57	213	580
43	Ogden	S	3-10-13	7.75	29.08	5.9	20.1	.10	.09	.08	35	65	60	214	390
44	Ogden	S	3-13-13	6.5	28.59	5.4	19.4	.08	.08	.07	34	71	61	215	450
37	Ogden	S	1-23-13	8.0	29.02	5.0	19.2	.14	.11	.10	31	68	53	214	594
38	Ogden	L	1-28-13	7.5	29.14	5.0	19.3	.13	.12	.10	25	67	58	213	470
45	Ogden	S	3-14-13	3.0	28.10	5.0	18.8	.12	.02	.01	40	61	58	212	965
2	Saylor	S	3-15-12	7.67	29.08	4.85	19.15	.123	.062	.069	24	66	53	216	663
5	Saylor	L	3-21-12	7.5	29.4	3.51	17.91	.091	.077	.078	20	66	58	213	535
31	Empire Lump	S	11-13-12	7.75	29.05	5.0	19.2	.125	.10	.09	44	62	59	214	700
34	Empire Lump	L	12- 4-12	6.75	28.85	4.9	19.0	.12	.09	.06	43	60	56	213	600
19	Empire Nut	S	7-15-12	7.5	29.31	6.0	20.4	.118	.101	.092	68	74	65	213.7	540
20	Empire Nut	L	7-16-12	7.16	29.24	5.5	19.8	.113	.096	.080	75	77	66	214	550
7	Little Jack	S	3-29-12	8.0	29.00	5.03	19.23	.142	.092	.092	44	68	61	213.3	625
12	Little Jack	S	5-20-12	8.0	29.00	4.80	19.1	.125	.088	.086	67	75	65	213	601
21	Little Jack	L	7-17-12	9.0	29.24	5.5	19.8	.111	.097	.080	73	80	68	214	530
16	Illinois Mine Run	S	6-13-12	7.67	28.78	5.8	19.98	.081	.07	.07	64	75	67	212.2	333
13	Illinois Mine Run	S	6- 5-12	7.67	29.15	6.7	21.07	.11	.10	.09	57	69	64	215	400

17	Illinois Mine Run	S	6-14-12	8.0	28.62	4.9	19.02	.127	.11	.09	70	80	67	213.1	652
1	Illinois Mine Run	S	3-11-12	8.0	28.92	4.77	18.97	.125	.095	.095	28	62	63	213.5	650
14	Illinois Mine Run	S	6- 7-12	8.0	29.38	4.1	18.58	.13	.08	.06	73	73	59	213.5	746
15	Illinois Mine Run	S	6-12-12	7.5	29.11	3.2	17.55	.136	.06	.01	70	78	67	212.5	830
18	Illinois Mine Run	S	6-16-12	7.33	29.20	3.4	17.80	.139	.07	.01	65	73	63	211.8	810
39	Illinois Pea-coal	S	2-21-13	7.33	29.00	5.0	19.2	.12	.10	.08	27	65	61	214	562
40	Illinois Pea-coal	L	2-25-13	7.5	29.10	5.0	19.2	.14	.11	.10	25	63	55	214	577
29	Kentucky Red Torch	S	10-28-12	8.0	28.81	5.0	19.1	.12	.10	.095	65	73	63	213	5[illegible]0
30	Kentucky Red Torch	L	10-29-12	7.67	29.01	5.0	19.2	.13	.10	.09	46	64	59	213	550
35	Tennessee Smokeless	L	12- 9-12	8.25	29.16	5.0	19.3	.10	.08	.07	30	58	57	214	500
6	Foundry Coke	S	3-28-12	8.0	28.75	4.05	18.15	.098	.057	.048	45	69	57	213	540
8	Gas-house Coke	S	3-30-12	8.67	29.11	5.03	19.33	.096	.057	.052	47	76	60	213.2	520
11	Gas-house Coke	S	5-16-12	8.5	29.01	4.84	19.14	.12	.08	.073	58	70	59	215	590
48	Petroleum Coke	L	5- 8-13	8.0	29.20	5.5	19.8	.11	.09	.08	64	70	57	213	532
22	Solvay Coke	S	7-18-12	8.16	29.36	5.55	19.95	.10	.092	.08	70	76	67	214	493
23	Solvay Coke	L	7-19-12	7.33	29.28	5.3	19.7	.111	.101	.086	61	68	64	214	473
36	Egg Anthracite	L	12-10-12	7.5	29.03	5.0	19.2	.15	.10	.07	33	64	59	214	492
9	Pea-anthracite	S	4- 1-12	9.67	29.00	4.95	19.15	.11	.065	.044	55	65	57	213.7	525
49	Iowa Peat	S	5-20-13	3.33	28.86	5.2	19.3	.12	.07	.03	56	63	57	214	625
10	Gas-house Coke and Saylor	S	4-11-12	8.08	28.95	5.23	19.43	.098	.067	.063	65	70	60	214.2	627
25	Solvay and Boone	L	7-23-12	5.5	28.90	5.38	10.58	.102	.085	.071	92	92	67	214	545
26	Solvay and Boone	L	7-24-12	5.67	29.02	6.10	20.3	.104	.092	.082	84	85	72	214	504

Symbols—S=short firing test. L=long firing test.
Test No. 10—1 pound of Gas-house coke to 2 pounds of Saylor lump coal well mixed.
Test No. 25—1 pound of Solvay coke to 1 pound of Boone lump coal, with coke fired on top of coal.
Test No. 26—1 pound of Solvay coke to 1 pound of Boone lump coal well mixed.

TABLE XIII.

DETAIL DATA ON INDIVIDUAL TESTS (Continued

Test Number	Kind of Fuel	Kind of Firing	Average Flue Gas Analysis (% by Volume)				Ratio of Air Supplied to Air Used	Pounds Air Supplied Per Pound Carbon	Analysis of Fuel						
									Proximate, Fuel as Fired (% by Weight)				Calorific (B. T. U. per Pound)		
			CO_2	Oxygen	C O	Nitrogen and Undetermined			Moisture	Volatile Matter	Fixed Carbon	Ash	As Fired	Dry	Combustible
1	2	3	17	18	19	20	21	22	23	24	25	26	27	28	29
3	Boone	S	9.2	9.7	-------	81.1	1.83	21.4	10.4	39.8	39.0	10.8	10,600	11,820	13,440
4	Boone	S	9.6	8.9	-------	81.5	1.71	20.0	8.5	39.6	39.0	12.9	10,550	11,530	13,410
24	Boone	S	10.5	5.7	1.5	82.3	1.36	15.9	11.2	37.2	41.3	10.3	10,800	12,150	13,750
27	Boone	S	8.9	7.6	-------	83.5	1.53	17.9	8.7	34.5	40.0	16.8	10,400	11,380	13,900
28	Boone	L	11.5	5.3	-------	83.2	1.32	15.4	8.7	34.5	40.0	16.8	10,400	11,380	13,900
46	Buxton	L	13.0	5.6	-------	81.4	1.35	15.8	8.2	36.5	43.7	11.6	10,600	11,530	13,180
47	Buxton	L	12.9	6.2	-------	80.9	1.41	16.5	8.2	36.5	43.7	11.6	10,600	11,530	13,180
41	Centerville	S	13.0	6.0	-------	81.0	1.39	16.3	9.2	37.5	46.5	6.8	12,450	13,700	14,810
42	Centerville	L	12.5	6.3	-------	81.2	1.42	16.6	9.2	37.5	46.5	6.8	12,450	13,700	14,810
32	Colfax	S	13.1	4.5	-------	82.4	1.26	14.7	8.5	39.1	42.2	10.2	11,540	12,610	14,180
33	Colfax	L	12.4	6.6	-------	81.0	1.45	17.0	8.5	39.1	42.2	10.2	11,540	12,610	14,180
43	Ogden	S	10.3	8.5	-------	81.2	1.66	19.4	11.3	38.4	39.1	11.2	10,300	11,600	13,270
44	Ogden	S	13.8	4.5	-------	81.7	1.26	14.7	10.8	38.4	40.6	10.2	10,270	11,500	12,960
37	Ogden	S	13.1	5.6	-------	81.3	1.35	15.8	12.0	40.4	41.0	6.6	11,550	13,130	14,200
38	Ogden	L	14.2	4.0	-------	81.8	1.23	14.4	12.0	40.4	41.0	6.6	11,550	13,130	14,200
45	Ogden	S	15.8	2.1	-------	82.1	1.11	13.0	10.8	38.4	40.6	10.2	10,270	11,500	12,960
2	Saylor	S	10.0	8.8	-------	81.2	1.70	19.9	7.2	39.5	43.0	10.3	11,620	12,520	14,100
5	Saylor	L	11.2	6.1	-------	82.7	1.39	16.3	3.9	42.1	41.9	12.1	11,800	12,280	14,020
31	Empire Lump	S	12.6	3.8	-------	83.6	1.21	14.2	6.9	37.3	44.1	11.7	11,520	12,380	14,160
34	Empire Lump	L	14.4	4.6	-------	81.0	1.28	15.0	6.9	37.3	44.1	11.7	11,520	12,380	14,160
19	Empire Nut	S	12.4	5.0	-------	82.6	1.30	15.2	8.3	33.9	45.4	12.4	11,400	12,450	14,400
20	Empire Nut	L	11.1	5.9	-------	83.0	1.37	16.0	8.3	33.9	45.4	12.4	11,400	12,450	14,400
7	Little Jack	S	12.1	5.5	-------	82.4	1.31	15.7	5.5	33.0	55.0	6.5	11,800	12,490	13,400
12	Little Jack	S	10.6	7.6	-------	81.8	1.55	18.1	5.8	29.2	56.9	8.1	11,800	12,530	13,700
21	Little Jack	L	13.0	4.2	-------	82.8	1.24	14.5	6.0	33.2	52.6	8.2	12,700	13,500	14,800

16	Illinois Mine Run	S	6.4	12.9	0.1	80.6	2.56	30.0	10.4	33.3	41.9	14.4	10,450	11,670	13,890
13	Illinois Mine Run	S	10.0	6.8	0.4	82.8	1.45	17.0	10.4	33.3	41.9	14.4	10,450	11,670	13,890
17	Illinois Mine Run	S	10.7	6.5	0.1	82.7	1.43	16.7	10.4	33.3	41.9	14.4	10,450	11,670	13,890
1	Illinois Mine Run	S	10.4	8.8	..	80.8	1.70	19.9	7.3	34.0	41.0	17.7	10,700	11,550	14,250
14	Illinois Mine Run	S	10.6	6.6	0.5	82.3	1.44	16.9	10.4	33.3	41.9	14.4	10,450	11,670	13,890
15	Illinois Mine Run	S	13.1	3.5	0.2	83.2	1.19	13.9	10.4	33.3	41.9	14.4	10,450	11,670	13,890
18	Illinois Mine Run	S	12.2	4.3	0.4	83.1	1.24	14.5	10.4	33.3	41.9	14.4	10,450	11,670	13,890
39	Illinois Pea-coal	S	13.6	4.4	..	82.0	1.25	14.6	7.1	35.6	43.8	13.5	11,350	12,220	14,280
40	Illinois Pea-coal	L	13.2	5.3	..	81.5	1.33	15.6	7.1	35.6	43.8	13.5	11,350	12,220	14,280
29	Kentucky Red Torch	S	11.4	6.0	..	82.6	1.38	16.1	2.0	38.5	56.2	3.3	14,800	15,100	15,650
30	Kentucky Red Torch	L	13.1	5.5	..	81.4	1.34	15.7	2.0	38.5	56.2	3.3	14,800	15,100	15,650
35	Tennessee Smokeless	L	14.4	4.9	..	80.7	1.30	15.2	0.9	15.9	68.3	14.9	13,190	13,310	15,640
6	Foundry Coke	S	9.2	10.7	..	80.1	2.03	23.8	1.1	2.0	84.0	12.9	12,630	12,780	14,690
8	Gas-house Coke	S	9.6	10.0	..	80.4	1.89	22.1	1.3	3.2	83.9	11.6	12,570	12,730	14,420
11	Gas-house Coke	S	7.6	12.4	..	80.0	2.44	28.6	2.1	1.6	80.7	15.6	12,000	12,250	14,550
48	Petroleum Coke	L	14.0	4.9	..	81.1	1.29	15.2	1.7	10.3	86.1	1.9	14,850	15,110	15,450
22	Solvay Coke	S	11.6	7.3	..	81.1	1.52	17.8	0.5	2.0	86.6	10.9	12,880	12,950	14,530
23	Solvay Coke	L	12.2	6.1	..	81.7	1.42	16.6	0.5	2.0	86.6	10.9	12,880	12,950	14,530
36	Egg Anthracite	L	11.9	8.4	..	79.7	1.67	19.5	1.4	6.1	86.3	6.2	13,740	13,940	14,880
9	Pea-anthracite	S	7.2	12.3	..	80.5	2.39	28.0	2.4	6.8	79.5	11.3	13 020	13,350	15,090
49	Iowa Peat	S	13.9	5.1	..	81.0	1.31	15.4	45.2	25.8	12.5	16.5	3,500	6,390	9,130
10	Gas-house Coke and Saylor	S	8.2	10.4	..	81.4	1.94	22.7	5.9	22.3	56.0	15.8	11,030	11,730	14,100
25	Solvay and Boone	L	12.7	6.2	0.0	81.1	1.41	16.5	4.7	20.0	64.0	11.3	12,040	12 650	14,350
26	Solvay and Boone	L	11.8	6.7	0.5	81.0	1.46	17.1	4.7	20.0	64.0	11.3	12,040	12,650	14,350

TABLE XIII

DETAIL DATA ON INDIVIDUAL TESTS

Test Number	Kind of Fuel	Kind of Firing	Total Fuel Used for Test (pounds): As Fired	Total Fuel Used for Test (pounds): Dry	Total Fuel Used for Test (pounds): Combustible Consumed	Ash and Refuse: Total Pounds	Ash and Refuse: Per Cent of Fuel as Fired	Ash and Refuse: Per Cent Carbon	Ash and Refuse: Per Cent Ash	Ash and Refuse: B. T. U, per Pound Dry Fuel	Hourly Fuel Quantities: Pounds: Fuel as Fired	Hourly Fuel Quantities: Pounds: Dry Fuel	Hourly Fuel Quantities: Pounds: Combustible Consumed	Hourly Fuel Quantities: Fuel as Fired Per sq. ft. Grate Surface	Hourly Fuel Quantities: B. T. U. Supplied: In Dry Fuel	Hourly Fuel Quantities: B. T. U. Supplied: In Combustible Consumed
1	2	3	30	31	32	33	34	35	36	37	38	39	40	41	42	43
3	Boone	S	300	269	226	40	13.3	27.0	73.0	540	37.5	33.6	28.2	5.51	400,000	379,000
4	Boone	S	330	302	252	40	12.1	17.7	82.3	314	40.8	37.3	31.1	6.00	430,000	417,000
24	Boone	S	365	324	249	75	20.5	49.8	50.2	1,670	57.6	51.2	39.4	8.47	622,000	543,000
27	Boone	S	300	274	213	61	20.3	18.0	82.0	560	41.3	37.8	29.3	6.08	430,000	408,000
28	Boone	L	300	274	217	57	19.0	12.3	87.7	350	41.3	37.8	29.9	6.08	430,000	416,000
46	Buxton	L	300	275	227	48	16.0	27.5	72.5	695	35.3	32.3	26.7	5.19	372,500	352,000
47	Buxton	L	300	275	228	47	15.7	26.0	74.0	645	36.3	33.3	27.6	5.33	384,000	364,000
41	Centerville	S	300	272	232	40	13.3	49.0	51.0	1,040	39.1	35.5	30.3	5.75	486,000	448,000
42	Centerville	L	300	272	234	38	12.7	46.3	53.7	940	36.3	32.9	28.3	5.33	451,000	420,000
32	Colfax	S	300	275	223	52	17.3	40.4	59.6	1,130	41.3	37.9	30.7	6.08	478,000	436,000
33	Colfax	L	300	275	224	51	17.0	39.2	60.8	1,080	38.7	35.5	28.9	5.68	448,000	410,000
43	Ogden	S	175	155	134	21	12.0	6.6	93.4	130	22.5	20.0	17.3	3.30	232,000	229,500
44	Ogden	S	200	178	154	24	12.0	15.0	85.0	290	30.7	27.4	23.7	4.51	315,000	307,000
37	Ogden	S	300	264	229	35	11.7	43.5	56.5	840	37.5	33.0	28.6	5.51	434,000	406,000
38	Ogden	L	300	264	233	31	10.3	36.0	64.0	620	40.0	35.2	31.0	5.88	463,000	440,500
45	Ogden	S	200	178	152	26	13.0	21.5	78.5	460	66.7	59.3	50.6	9.80	682,000	655,000
2	Saylor	S	270	251	207	46	17.0	34.9	65.1	900	35.2	32.8	26.9	5.17	411,000	380,000
5	Saylor	L	250	240	188	50	20.0	44.3	55.7	1,280	33.3	32.0	25.0	4.90	393,000	351,000
31	Empire Lump	S	300	279	234	45	15.0	22.2	77.8	520	38.7	36.0	30.2	5.68	446,000	428,000
34	Empire Lump	L	250	233	194	39	15.6	35.6	74.4	620	37.0	34.5	28.7	5.43	427,000	406,000
19	Empire Nut	S	285	261	208	53	18.6	33.2	66.8	990	38.0	34.8	27.7	5.68	433,000	399,000
20	Empire Nut	L	250	229	183	46	18.4	32.5	67.5	950	34.9	32.0	25.5	5.13	398,000	367,000
7	Little Jack	S	250	236	209	31	12.4	34.3	65.7	620	31.2	29.5	26.1	4.58	369,000	350,000
12	Little Jack	S	250	235	203	33	13.2	35.2	64.8	680	31.2	29.4	25.4	4.58	369,000	348,000
21	Little Jack	L	260	244	197	47	18.1	54.7	45.3	1,530	29.0	27.1	21.9	4.26	366,000	324,000

16	Illinois Mine Run -------	S	125	112	74	38	30.4	52.7	47.3	2,600	16.3	14.6	9.7	2.39	170,000	134,500
17	Illinois Mine Run -------	S	150	134	94	40	26.6	46.0	54.0	2,040	19.6	17.5	12.3	2.88	204,000	171,000
13	Illinois Mine Run -------	S	280	251	187	64	22.9	37.0	63.0	1,370	35.0	31.4	23.4	5.14	366,000	[illegible]
1	Illinois Mine Run -------	S	260	241	179	58	22.3	28.0	72.0	960	32.5	30.1	22.4	4.78	348,000	319,000
14	Illinois Mine Run -------	S	425	381	299	82	19.3	25.4	74.6	800	53.1	47.6	37.4	7.80	555,000	520,000
15	Illinois Mine Run -------	S	550	493	392	101	18.3	21.8	78.2	650	73.3	65.7	52.2	10.78	766,000	725,000
18	Illinois Mine Run -------	S	550	493	372	121	22.0	34.5	65.5	1,230	75.0	67.1	50.8	11.02	784,000	705,000
39	Illinois Pea-coal --------	S	300	279	226	53	17.7	23.5	76.5	650	40.8	38.0	30.8	6.00	465,000	440,000
40	Illinois Pea-coal --------	L	300	279	229	50	16.7	19.0	81.0	490	40.0	37.2	30.5	5.88	455,000	435,000
29	Kentucky Red Torch ----	S	250	245	202	43	17.2	81.5	18.5	2,150	31.2	30.6	25.2	4.58	462,000	395,000
30	Kentucy Red Torch ----	L	250	245	206	39	15.6	79.0	21.0	1,920	32.6	31.9	26.8	4.79	482,000	419,000
35	Tennessee Smokeless ----	L	200	198	163	35	17.5	14.3	85.7	370	24.2	24.0	19.7	3.55	319,000	308,000
6	Foundry Coke ----------	S	200	198	165	33	16.5	21.2	78.8	510	25.0	24.7	20.6	3.67	315,000	303,000
8	Gas-house Coke ---------	S	200	197	163	37	18.5	30.3	69.7	820	23.1	22.7	18.8	3.40	289,000	271,000
11	Gas-house Coke ---------	S	250	245	192	48	19.2	28.6	71.4	800	29.4	28.8	22.6	4.32	353,000	330,000
48	Petroleum Coke ---------	L	200	197	173	24	12.0	84.2	15.8	1,485	25.0	24.6	21.6	3.67	372,000	334,000
22	Solvay Coke ------------	S	200	199	152	47	23.5	53.7	46.3	1,830	24.5	24.4	18.6	3.60	316,000	270,000
23	Solvay Coke ------------	L	175	173	136	38	21.7	49.7	50.3	1,570	23.9	23.6	18.5	3.51	306,000	269,000
36	Egg Anthracite ---------	L	200	197	159	38	19.0	68.5	31.5	1,890	26.7	26.3	21.2	3.92	367,000	315,000
9	Pea-anthracite ----------	S	250	244	195	47	18.8	44.9	55.1	1,275	25.8	25.2	20.3	3.79	337,000	306,000
49	Iowa Peat ---------------	S	350	192	126	66	18.9	12.5	87.5	625	105.0	57.6	37.8	15.40	368,000	345,000
19	Gas-house Coke & Saylor	S	275	259	204	43	15.6	25.2	74.8	575	34.0	32.0	25.2	5.00	376,000	356,000
26	Solvay and Boone-------	L	200	191	150	41	20.5	44.9	55.1	1,400	36.3	34.7	27.2	5.33	438,000	390,000
25	Solvay and Boone-------	L	200	191	151	40	20.0	43.5	56.5	1,320	35.3	33.7	26.6	5.19	426,000	382,000

TABLE XI

DETAIL DATA ON INDIVIDUAL TESTS

Test Number	Kind of Fuel	Kind of Firing	Quality of Steam (%)	Factor of Evaporation	Total Evaporation (pounds): Actual Water	Total Evaporation (pounds): Dry Steam	Total Evaporation (pounds): Equive.Evap from and at 212 oF.	Hourly Evaporation (pounds): Actual Water	Hourly Evaporation (pounds): Dry Steam	Hourly Evaporation (pounds): Equiv. Evap. from and at 212 oF.	Hourly Evaporation (pounds): Equiv. Evap. (212oF.) per sq. ft. Boiler Heating Surface	B. T. U. Absorbed Per Hour: By Steam	B. T. U. Absorbed Per Hour: Per Pound Dry Fuel	B. T. U. Absorbed Per Hour: Per Pound Combustible Consumed
1	2	3	44	45	46	47	48	49	50	51	52	53	54	55
3	Boone	S	99.6	1.175	1,392	1,388	1,630	174	173	204	2.60	197,500	5,880	7,000
4	Boone	S	99.7	1.162	1,440	1,436	1,670	178	177	207	2.63	201,000	5,390	6,460
24	Boone	S	99.5	1.155	1,115	1,109	1,280	176	175	202	2.57	196,000	3,830	4,970
27	Boone	S	99.6	1.163	1,214	1,209	1,405	167	166	194	2.47	188,000	4,980	6,420
28	Boone	L	99.5	1.161	1,283	1,280	1,486	177	176	205	2.60	199,000	5,270	6,660
46	Buxton	L	99.6	1.163	1,501	1,495	1,740	177	176	204	2.60	198,500	6,140	7,430
47	Buxton	L	99.5	1.161	1,410	1,403	1,630	171	170	197	2.51	191,500	5,750	6,940
41	Centerville	S	99.5	1.132	1,392	1,385	1,610	181	180	210	2.67	203,500	5,730	6,710
42	Centerville	L	99.5	1.165	1,570	1,562	1,820	190	189	221	2.81	214,500	6,510	7,580
32	Colfax	S	99.5	1.163	1,300	1,293	1,502	179	178	207	2.64	201,000	5,300	6,550
33	Colfax	L	99.6	1.164	1,382	1,376	1,602	178	177	207	2.64	201,000	5,660	6,960
43	Ogden	S	99.6	1.160	769	766	889	99.2	98.8	115	1.45	111,500	5,570	6,450
44	Ogden	S	99.6	1.160	874	871	1,010	135	134	155	1.97	150,500	5,480	6,350
37	Ogden	S	99.6	1.169	1,414	1,408	1,645	177	176	206	2.62	200,000	6,060	6,990
38	Ogden	L	99.5	1.162	1,337	1,330	1,548	178	177	206	2.62	200,000	5,680	6,450
45	Ogden	S	99.5	1.162	858	854	993	286	285	331	4.22	331,000	5,420	6,350
2	Saylor	S	99.7	1.169	1,210	1,206	1,410	158	157	184	2.34	178,400	5,450	6,630
5	Saylor	L	99.6	1.163	1,148	1,143	1,330		152	177	2.25	172,000	5,370	6,880
31	Empire Lump	S	99.5	1.162	1,425	1,418	1,648	184	183	213	2.71	207,000	5,750	6,860
34	Empire Lump	L	99.6	1.165	1,325	1,320	1,538	196	195	2[illegible]7	2.90	220,000	6,370	7,670
19	Empire Nut	S	99.3	1.159	1,310	1,301	1,507	17[illegible]	173	201	2.55	195,000	5,600	7,040
20	Empire Nut	L	99.5	1.156	1,248	1,242	1,436	174	173	200	2.54	194,000	6,060	7,610
7	Little Jack	S	99.4	1.160	1,417	1,408	1,630	177	176	204	2.60	197,500	6,690	7,570
12	Little Jack	S	99.6	1.157	1,523	1,517	1,755	190	189	219	2.78	212,800	7,240	8,380
21	Little Jack	L	99.5	1.152	1,668	1,660	1,915	185	184	213	2.71	206,500	7,620	9,440

16	Illinois Mine Run	S	99.4	1.155	549	546	632	72	71	82	1.04	79,600	5,450	8,200
13	Illinois Mine Run	S	99.6	1.160	906	902	1,047	118	117	136	1.73	132,300	7,550	10,750
17	Illinois Mine Run	S	99.6	1.155	1,383	1,378	1,590	173	172	199	2.53	193,000	6,150	8,250
1	Illinois Mine Run	S	99.6	1.160	1,248	1,243	1,440	156	155	180	2.28	174,800	5,810	7,780
14	Illinois Mine Run	S	99.5	1.162	2,074	2,064	2,400	259	258	300	3.82	291,000	6,120	7,800
15	Illinois Mine Run	S	99.7	1.152	2,188	2,182	2,520	292	291	325	4.25	324,000	4,930	6,210
18	Illinois Mine Run	S	99.7	1.158	2,234	2,227	2,580	305	304	352	4.47	341,500	5,090	6,720
39	Illinois Pea-coal	S	99.5	1.160	1,252	1,246	1,445	171	170	197	2.51	191,000	5,020	6,200
40	Illinois Pea-coal	L	99.5	1.167	1,355	1,348	1,570	181	180	209	2.67	203,000	5,460	6,630
29	Kentucky Red Torch	S	99.6	1.159	1,387	1,382	1,602	173	172	200	2.55	194,000	6,340	7,700
30	Kentucky Red Torch	L	99.5	1.162	1,436	1,429	1,660	187	186	217	2.76	210,000	6,580	7,830
35	Tennessee Smokeless	L	99.5	1.161	1,503	1,495	1,740	182	181	211	2.69	205,000	8,550	10,400
6	Foundry Coke	S	99.6	1.165	1,170	1,165	1,360	146	145	170	2.16	164,900	6,680	8,000
8	Gas-house Coke	S	99.5	1.162	1,465	1,458	1,695	169	168	195	2.48	190,100	8,380	10,110
11	Gas-house Coke	S	99.6	1.162	1,482	1,476	1,715	174	173	202	2.56	196,000	6,800	8,660
48	Petroleum Coke	L	99.5	1.166	1,372	1,365	1,592	172	171	199	2.53	193,000	7,840	8,930
22	Solvay Coke	S	99.4	1.155	1,466	1,457	1,683	179	178	206	2.62	200,000	8,200	10,750
23	Solvay Coke	L	99.5	1.159	1,365	1,358	1,573	186	185	215	2.74	208,000	8,820	11,250
36	Egg Anthracite	L	99.5	1.163	1,345	1,338	1,556	179	178	207	2.64	201,000	7,640	9,490
9	Pea-anthracite	S	99.7	1.165	1,625	1,620	1,890	168	167	195	2.48	190,100	7,550	9,380
49	Iowa Peat	S	99.5	1.166	470	468	546	141	140	164	2.09	159,000	2,760	4,210
10	Gas-house Coke and Saylor	S	99.6	1.160	1,480	1,474	1,710	183	182	211	2.68	205,000	6,410	8,150
25	Solvay and Boone	L	99.5	1.154	1,046	1,041	1,200	190	189	218	2.77	211,500	6,100	7,780
26	Solvay and Boone	L	99.3	1.150	1,056	1,049	1,205	186	185	212	2.70	205,500	6,110	7,730

TABLE XIII.

DETAIL DATA ON INDIVIDUAL TESTS

Test Number	Kind of Fuel	Kind of Firing	Fuel Charges: Number During Test	Fuel Charges: Average Time Between (hours)	Fuel Charges: Average Weight (pounds)	Average Capacity developed: Boiler Horse Power	Average Capacity developed: Sq. Ft. of Radiation	Average Capacity developed: Per Cent of Builders rating	Evaporative Performance, Fuel as Fired, Per Pound: Actual Evaporation (pounds)	Evaporative Performance, Fuel as Fired, Per Pound: Equiv. Evap (212 oF) (pounds)	Evaporative Performance, Fuel as Fired: Lbs. Fuel per 100 sq. ft. Rad per Hr.	Evaporative Performance, Per Pound Combustibe: Actual Evaporation (Pounds)	Evaporative Performance, Per Pound Combustibe: Equiv. Evap (212o F) (pounds)	Efficiencies: Boiler (%)	Efficiencies: Boiler and Grate (%)
1	2	3	56	57	58	59	60	61	62	63	64	65	66	67	68
3	Boone	S	3	2.67	100	5.91	816	60.4	4.64	5.43	4.59	5.89	6.89	52.0	49.7
4	Boone	S	4	2.02	82.5	6.00	826	61.2	4.36	5.06	4.94	5.54	6.44	48.2	46.8
24	Boone	S	2	3.16	182.5	5.86	807	59.8	3.06	3.51	7.15	3.90	4.47	36.1	31.5
27	Boone	S	3	2.42	100	5.62	776	57.5	4.05	4.68	5.33	5.43	6.28	46.1	43.8
28	Boone	L	1	7.25	300	5.93	819	60.6	4.29	4.95	5.05	5.76	6.64	47.9	46.3
46	Buxton	L	1	8.50	300	5.92	817	60.5	5.00	5.80	4.32	6.23	7.23	56.3	53.3
47	Buxton	L	1	8.25	300	5.73	789	58.4	4.70	5.43	4.60	5.86	6.77	52.6	49.8
41	Centerville	S	3	2.56	100	6.09	840	62.2	4.64	5.37	4.66	5.52	6.38	45.4	41.8
42	Centerville	L	1	8.25	300	6.40	885	65.5	5.23	6.07	4.10	6.23	7.26	51.0	47.5
32	Colfax	S	3	2.42	100	6.00	830	61.4	4.33	5.01	4.98	5.32	6.14	46.1	42.0
33	Colfax	L	1	7.75	300	6.00	830	61.4	4.61	5.34	4.67	5.67	6.57	49.0	44.8
43	Ogden	S	3	2.58	58	3.30	457	33.8	4.39	5.08	4.93	5.66	6.55	48.6	48.1
44	Ogden	S	2	3.75	100	4.48	620	45.9	4.37	5.05	4.96	5.52	6.39	49.0	47.8
37	Ogden	S	3	2.67	100	5.95	923	60.9	4.71	5.48	4.56	5.78	6.73	49.3	46.1
38	Ogden	L	1	7.50	300	5.95	823	60.9	4.46	5.16	4.86	5.47	6.33	45.4	43.2
45	Ogden	S	2	1.50	100	9.60	1,328	98.3	4.29	4.96	5.02	5.43	6.27	49.1	47.1
2	Saylor	S	3	2.56	90	5.33	735	54.4	4.48	5.22	5.79	5.42	6.32	47.0	43.5
5	Saylor	L	1	7.50	250	5.13	706	52.3	4.60	5.32	4.72	5.48	6.33	49.1	45.8
31	Empire Lump	S	3	2.58	100	6.17	853	63.1	4.75	5.49	4.53	5.83	6.73	48.2	46.4
34	Empire Lump	L	1	6.75	250	6.58	910	67.3	5.30	6.15	4.06	6.51	7.54	54.1	51.5
19	Empire Nut	S	3	[illegible].50	95	5.83	803	59.5	4.60	5.29	4.73	5.80	6.67	48.9	45.0
20	Empire Nut	L	1	7.16	250	5.80	800	59.2	5.00	5.75	4.36	6.31	7.26	52.9	48.8
7	Little Jack	S	3	2.67	83.3	5.91	816	60.4	5.67	6.52	3.82	6.43	7.41	56.6	53.6
12	Little Jack	S	3	2.67	83.3	6.35	875	64.8	6.10	7.02	3.57	7.08	8.15	61.2	57.7
21	Little Jack	L	1	9.00	260	6.18	851	63.0	6.41	7.37	3.41	7.47	8.60	63.7	56.4

16	Illinois Mine Run	S	2	3.83	62.5	2.36	328	24.3	4.39	5.06	4.96	5.85	6.73	59.1	46.8
13	Illinois Mine Run	S	2	3.88	75	3.94	543	40.2	6.04	6.98	3.61	8.03	9.29	77.4	64.7
17	Illinois Mine Run	S	3	2.67	93.3	5.77	795	58.9	4.94	5.68	4.40	6.57	7.55	59.4	52.7
1	Illinois Mine Run	S	3	2.67	86.7	5.22	718	53.2	4.80	5.54	4.53	6.40	7.40	54.7	50.3
14	Illinois Mine Run	S	5	2.67	141.7	8.70	1,200	88.8	4.88	5.65	4.42	6.49	7.51	56.0	52.5
15	Illinois Mine Run	S	5	1.50	110	9.72	1,339	99.2	3.98	4.58	5.47	5.29	6.10	44.7	42.3
18	Illinois Mine Run	S	11	0.67	50	10.20	1,408	104.2	4.06	4.70	5.33	5.40	6.25	48.4	43.6
39	Illinois Pea-coal	S	5	1.46	60	5.70	788	58.3	4.17	4.82	5.13	5.25	6.08	43.4	41.1
40	Illinois Pea-coal	L	1	7.50	300	6.05	838	62.0	4.52	5.23	4.77	5.70	6.60	46.6	44.6
29	Kentucky Red Torch	S	3	2.67	83.3	5.80	801	59.3	5.55	6.41	3.89	5.86	6.77	49.2	42.1
30	Kentucky Red Torch	L	1	7.67	250	6.28	868	64.2	5.74	6.64	3.75	6.07	7.02	50.1	43.6
35	Tennessee Smokeless	L	1	8.25	200	6.11	845	62.5	7.51	8.70	2.86	8.91	10.31	66.5	64.2
6	Foundry Coke	S	3	2.67	66.7	4.93	680	50.3	5.85	6.80	3.67	6.80	7.90	54.5	52.3
8	Gas-house Coke	S	3	2.89	66.7	5.65	780	57.7	7.33	8.48	2.96	8.42	9.73	70.2	65.8
11	Gas-house Coke	S	3	2.83	83.3	5.86	806	59.7	5.93	6.86	3.65	7.20	8.32	59.4	55.5
48	Petroleum Coke	L	1	8.00	200	5.77	797	59.0	6.86	7.96	3.14	7.11	8.25	57.7	51.8
22	Solvay Coke	S	4	2.04	50	5.97	823	61.0	7.33	8.41	2.97	8.28	9.15	74.0	63.3
23	Solvay Coke	L	1	7.33	175	6.23	860	63.6	7.80	9.00	2.78	8.78	10.12	77.4	68.0
36	Egg Anthracite	L	1	7.50	200	6.00	830	61.4	6.72	7.78	3.21	7.28	8.43	63.8	54.8
9	Pea-anthracite	S	3	3.22	83.3	5.65	780	57.7	6.50	7.56	3.31	7.52	8.75	62.1	56.6
49	Iowa Peat	S	4	0.83	87.5	4.75	656	48.6	1.34	1.56	16.00	3.50	4.07	46.1	43.2
10	Gas-house Coke and Saylor	S	3	2.69	91.7	6.12	843	62.4	5.38	6.21	4.03	6.88	7.93	57.7	54.6
25	Solvay and Boone	L	1	5.50	200	6.32	871	64.5	5.23	6.00	4.17	6.23	7.14	54.2	48.2
26	Solvay and Boone	L	1	5.67	200	6.15	849	62.8	5.28	6.03	4.16	6.29	7.18	53.8	48.2

TABLE XIII.

DETAIL DATA ON INDIVIDUAL TESTS (Continued

Test Number	Kind of Fuel	Kind of Firing	Costs								Boiler Heat Balance (by per cents)					
					Evaporative (¢)											
					At Actual Price			At $1.00 Per 2,000 lbs.								
			Per Ton of 2,000 lbs. ($)	Per Million B. T. U. (¢)	Per 1,000 lb Actual Evaporation	Per 1,000 lb Equiv. Evap. (212 oF)	Per 100 sq. ft. Radiation Per Hour	Per 1,000 lb Actual Evaporation	Per 1,000 lb Equiv. Evap. (212 oF)	Per 100 sq. ft. Radiation Per Hour	Heating and Evaporating Water	Heating Flue Gases	Heating and Evaporating Moisture n Fuel	Grate Losses	Unaccountd for	Total = Heat in Fuel as Fired
1	2	3	69	70	71	72	73	74	75	76	77	78	79	80	81	82
3	Boone	S	3.75	17.7	40.3	34.5	0.86	10.8	9.2	.230	49.7	20.0	1.6	4.6	24.1	100.0
4	Boone	S	3.75	17.8	43.0	37.0	0.93	11.5	9.9	.247	46.8	19.9	1.4	2.7	29.2	100.0
24	Boone	S	3.75	17.4	61.3	53.5	1.34	16.3	14.3	.358	31.5	10.2	1.1	13.7	43.5	100.0
27	Boone	S	3.75	18.0	46.3	40.0	1.00	12.4	10.7	.267	43.8	16.4	0.9	4.9	34.0	100.0
28	Boone	L	3.75	18.0	43.7	37.8	0.95	11.6	10.1	.253	46.3	12.4	0.9	3.1	37.3	100.0
46	Buxton	L	3.75	17.7	37.5	32.4	0.81	10.0	8.6	.216	53.3	13.7	1.1	6.0	25.9	100.0
47	Buxton	L	3.75	17.7	40.0	34.5	0.86	10.7	9.2	.230	49.8	13.7	1.0	5.6	29.9	100.0
41	Centerville	S	4.00	16.1	43.1	37.2	0.93	10.8	9.3	.233	41.8	14.1	1.0	7.6	35.5	100.0
42	Centerville	L	4.00	16.1	38.2	32.9	0.82	9.6	8.2	.205	47.5	13.5	0.9	6.9	31.2	100.0
32	Colfax	S	3.75	16.3	43.3	37.4	0.94	11.5	10.0	.249	42.0	13.7	0.9	9.0	34.4	100.0
33	Colfax	L	3.75	16.3	40.6	35.1	0.88	10.8	9.4	.234	44.8	14.6	0.9	8.6	31.1	100.0
43	Ogden	S	4.00	19.4	45.5	39.4	0.99	11.4	9.9	.247	48.1	10.9	1.1	1.1	38.8	100.0
44	Ogden	S	4.00	19.5	45.7	39.6	0.99	11.4	9.9	.248	47.8	9.6	1.1	2.5	39.0	100.0
37	Ogden	S	4.00	17.3	42.5	36.5	0.91	10.6	9.1	.228	46.1	13.7	1.3	6.4	32.5	100.0
38	Ogden	L	4.00	17.3	44.8	38.7	0.97	11.2	9.7	.242	43.2	9.8	1.2	4.7	41.1	100.0
45	Ogden	S	4.00	19.5	46.6	40.3	1.01	11.6	10.1	.251	47.1	20.0	1.3	4.0	27.6	100.0
2	Saylor	S	3.90	16.8	43.5	37.3	0.94	11.2	9.6	.240	43.5	19.4	1.3	7.2	28.6	100.0
5	Saylor	L	3.90	16.5	42.3	36.6	0.92	10.9	9.4	.235	43.8	12.1	0.5	10.4	33.2	100.0
31	Empire Lump	S	4.75	20.6	50.0	43.3	1.08	10.5	9.1	.227	46.4	16.1	0.7	4.2	32.6	100.0
34	Empire Lump	L	4.75	20.6	44.9	38.6	0.97	9.5	8.1	.203	51.5	14.1	0.7	5.0	28.7	100.0
19	Empire Nut	S	4.50	19.7	48.9	42.5	1.07	10.9	9.5	.237	45.0	11.5	0.8	8.0	34.7	100.0
20	Empire Nut	L	4.50	19.7	45.0	39.1	0.97	10.0	8.7	.218	48.8	12.3	0.8	7.6	30.5	100.0
7	Little Jack	S	5.50	19.1	48.6	42.2	1.05	8.8	7.7	.191	53.6	14.7	0.6	5.0	26.1	100.0
12	Little Jack	S	5.50	19.1	45.1	39.1	0.99	8.2	7.1	.179	57.7	15.7	0.7	5.4	20.5	100.0
21	Little Jack	L	5.50	17.7	42.9	37.3	0.94	7.8	6.8	.171	56.4	10.2	0.6	11.3	21.5	100.0

16	Illinois Mine Run	S	4.75	22.7	54.1	47.0	1.17	11.4	9.9	.247	46.8	10.8	1.1	22.3	19.0	100.0
13	Illinois Mine Run	S	4.75	22.7	39.2	34.0	0.86	8.2	7.2	.181	64.7	8.4	1.2	17.5	8.2	100.0
17	Illinois Mine Run	S	4.75	22.7	48.0	41.8	1.05	10.1	8.8	.220	52.7	15.0	1.3	11.7	19.3	100.0
1	Illinois Mine Run	S	4.75	22.2	49.5	42.9	1.08	10.4	9.0	.227	50.3	18.7	0.9	8.3	21.8	100.0
14	Illinois Mine Run	S	4.75	22.7	48.6	42.1	1.05	10.2	8.9	.221	52.5	18.7	1.4	6.9	20.5	100.0
15	Illinois Mine Run	S	4.75	22.7	59.7	51.9	1.30	12.6	10.9	.273	42.3	17.7	1.4	5.6	33.0	100.0
18	Illinois Mine Run	S	4.75	22.7	58.6	50.5	1.26	12.3	10.6	.266	43.2	17.3	1.4	10.5	27.6	100.0
39	Illinois Pea-coal	S	4.00	17.6	48.0	41.5	1.04	12.0	10.4	.259	41.1	12.1	0.7	5.3	40.8	100.0
40	Illinois Pea-coal	L	4.00	17.6	44.2	38.2	0.96	11.1	9.6	.239	44.6	13.6	0.7	4.0	37.1	100.0
29	Kentucky Red Torch	S	6.50	21.9	58.5	50.7	1.27	9.0	7.8	.195	42.1	11.3	0.2	14.2	32.2	100.0
30	Kentucky Red Torch	L	6.50	21.9	56.8	49.0	1.22	8.7	7.5	.188	43.6	12.3	0.2	12.7	31.2	100.0
35	Tennessee Smokeless	L	7.25	27.5	48.3	41.6	1.04	6.7	5.7	.143	64.2	11.9	0.1	2.8	21.0	100.0
6	Foundry Coke	S	8.50	33.6	72.7	62.6	1.56	8.6	7.4	.184	52.3	18.4	0.2	4.0	25.1	100.0
8	Gas-house Coke	S	7.00	27.8	47.8	41.3	1.03	6.8	5.9	.148	65.8	15.9	0.3	6.4	11.6	100.6
11	Gas-house Coke	S	7.00	29.2	59.0	51.0	1.28	8.4	7.3	.183	55.5	23.7	0.2	6.5	14.1	100.0
48	Petroleum Coke	L	10.25	34.5	74.7	64.3	1.61	7.3	6.3	.157	51.8	11.2	0.2	9.8	27.0	100.0
22	Solvay Coke	S	8.25	32.0	56.2	49.0	1.22	6.8	5.9	.148	63.3	11.1	0.1	14.1	11.4	100.0
23	Solvay Coke	L	8.25	32.0	52.8	45.8	1.15	6.4	5.6	.139	68.0	10.3	0.1	12.1	9.5	100.0
36	Egg Anthracite	L	10.25	37.3	76.2	65.8	1.65	7.4	6.4	.161	54.8	12.7	0.2	13.6	18.7	100.0
9	Pea-anthracite	S	8.75	33.6	67.3	57.8	1.44	7.7	6.6	.165	56.6	20.0	0.4	9.6	13.4	100.0
49	Iowa Peat	S	4.50	64.3	168.0	144.1	3.60	37.3	32.0	.801	43.2	13.7	17.0	9.8	16.3	100.0
10	Gas-house Coke & Saylor	S	4.93	22.4	45.7	39.7	0.99	9.3	8.0	.201	54.6	20.8	0.7	4.9	19.0	100.0
25	Solvay and Boone	L	6.00	24.9	57.5	50.0	1.25	9.6	8.3	.208	48.2	11.6	0.5	11.1	28.6	100.0
26	Solvay and Boone	L	6.00	24.9	57.0	49.8	1.24	9.5	8.3	.208	48.2	11.3	0.5	10.4	29.6	100.0

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